POSSIBLE DEVELOPMENTS OF BUILDING TECHNOLOGY

IN RELATION TO

LOW COST HOUSING IN PAKISTAN

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SUMMARY

This study relates the recent developments that have taken place in soil stabilization techniques to low-cost housing in Pakistan. The investigation has been carried out in three distinct phases.

The first phase of this study undertakes a brief review of the housebuilding in the country. A survey of the building materials in a selected region helped remove a handicap due to lack of factual information in this sphere. None of the existing building materials, due to their scarcity and high costs, was found to be within the means of the common man. Attention therefore had to be focused on earth which inspite of its shortcomings continues to provide shelter to a vast majority of the population in the Indus Plains. A study of earth housing in these plains as well as in some other developing countries helped isolate problems associated with the use of earth as building material. Rainfall, particularly in conjunction with winds, was found to be one of the important factors responsible for bringing this most abundant of the building materials into disrepute. In recent years an extensive use of soil stabilization techniques has been made in connection with the highway and airfield construction in other parts of the world. An application of the knowledge and experience gained in this field to revitalize earth housing is found to be the only realistic approach to the housing problem in the Indus Plains.

The second phase, which forms the core of this project, deals in classifying and locating the soils of the Indus Plains for the purpose of their planned use in stabilized earth housing. All soils encountered in the region are classified into major groups based on their identifiable characteristics significant from a stabilization viewpoint. This objective was achieved through the cooperation of a soil survey agency.

Soil information thus obtained is presented in the form of simple yet comprehensive Soil Maps. These maps provide ready information about all the important aspects of soil for undertaking a stabilized earth project. The problem of identifying the soil, upon which rests the whole success of this technique, is therefore almost completely solved. After the soil has been correctly identified it only remains to determine the requirements in terms of cement, water and compaction for achieving the desired results.

The third phase of this investigation was devised to determine the above requirements for each soil group so as to eliminate the need for elaborate testing on every site. This involved stabilization of representative samples of all major soil groups in the laboratory with varying amounts of Portland cement. The specimens thus prepared were tested for durability. Results obtained from soils stabilized with fairly low cement contents compared favourably with those of burnt brick. Based on these results the quantity of cement, amount of moisture and compactive effort needed for each soil group is recommended.

This study has thus provided answers to all the practical problems of soil stabilization for low cost housing in the form of simple reference maps.

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CONTENTS

LIST OF TABLES

Table	Page
31. States of Consistency	86.
32. Soil Reaction	88.
33. Analysis of the Soil Samples investigated for Durability	101.
34. Results of Durability Testing	102.
35. Specifications of the Smooth-Wheel Roller	112.
36. Field Compaction Results	114.
37. Comparison of Performance with Burnt Brick	117.

INTRODUCTION

The dilemma of someone who has set for himself the objective of making a realistic and practicable contribution to the solution of the problem of shelter in the third world may not easily be appreciated by a reader accustomed to usual research techniques. To enter this vast barren field, with mind set on a precisely defined objective, and remain immune to the devastating elements rampant therein was hardly possible. The identification and definition of the subject ultimately chosen for study has, therefore, in itself been the outcome of an evolutionary process. During the earlier stages, as the wide scope of the title of this study suggests, considerable search was made into the techniques of construction and methods of streamlining the building operations being used in the western countries for greater productivity and economy.

A critical look at the magnitude of the problem and the resources available soon brought home the point that a superficial marriage between the East and the West, as has been attempted in some countries by trying to import western building techniques as a package deal, cannot but result in failure. Though the marriage did take place, as would be seen in this study, yet it was at quite a different level and under radically different circumstances. Even a casual look at the results of the survey of building materials was enough to indicate that however efficient and streamlined be the building industry in Pakistan, which is almost non-existent in the housing sector at the moment, it would not be able to cope with the magnitude of the problem. Providing homes for the people at a price which they can afford is almost a universal problem but so acute in Pakistan that the dream of owning a healthy home with adequate minimum standards is realized only in the case of a handful.

It became evident that the price of the building materials was one of the most important stumbling-blocks to be reckoned with, particularly in the case of sub-urban and rural areas. If any attempt at improving the existing housing conditions is to be viable it must first of all aim at bringing about a drastic reduction in the cost of the building materials. A general survey of the existing earth-housing in Pakistan as well as in many other developing countries however revealed the paradoxical situation where the material though costing nothing has betrayed the confidence of its users due to its failure to stand up to the forces of the weather. The art of earth construction developed through centuries is, therefore, in the face of the weather coupled with the complex influences of the present day civilization, gradually falling into disrepute.

These factors led the author to cast a searching look into quite a different field from that of building construction - soil engineering. Major advances have occurred in soil engineering in airfield and road construction. Soil has proved beyond doubt to be an economical solution for these applications in many countries, particularly USA where many million square yards of stabilized earth work has been completed in recent years.

However, it seems somewhat amazing that this tremendous opportunity has not been seized by the building construction industry and no significant attempt has been made to reduce the time lag between the development of an important science and its application to one of the most fundamental of human problems - the shelter. A thorough search into literature on the subject revealed some attempts made in this direction but they have mostly been halfhearted and unscientific. The result in most cases therefore was a spectacular failure.

The nature and type of the soil has emerged as an all-important factor in this newly developed science of earth stabilization. It was, therefore, decided to explore the enormous soil resources of Pakistan from this angle. A detailed investigation of the soils in a selected region followed by a laboratory study of the behaviour of these soils, when stabilized with portland cement, forms the core of this project.

From the very nature of the problem it appears to be a trespass into many fields which would conventionally be considered outside the proper boundaries of Architecture. This in fact could have been one of the reasons why architects and builders have so far evaded indulgence into a field from which highway and airfield engineers have obtained rich dividends. The author decided to accept this challenge. All possible precautions were, however, taken to safeguard against any pitfalls by working in close co-operation with a number of experts and their staff well-versed in their respective fields. Without their enthusiastic support this project could not have progressed beyond inception. It indeed has been an inter-disciplinary exercise.

In order to make the results of this study directly applicable, not only has the written matter been kept to the bare minimum but also in the last part the gist of this thesis has been synthesised in the form of readily understandable and systematic information. This again may well be considered an oversimplification of the complex science of earth stabilization seen from an academic viewpoint; though quite in harmony with the author's original intentions which are to make this study of some use to the millions to whom it is dedicated. This study, in its present form and with its inherent inability to deal with many other important factors, can at best be described as a feasibility study. The possibilities and the necessities of further investigation in this field are so vast that this attempt is no more than a pointer to the direction in which may lie the solution to one of the fundamental problems of providing minimum standard housing to the exploding populations of the developing countries like Pakistan.

PART I

IDENTIFYING THE NEED FOR REVITALIZATION OF EARTH-HOUSING

CHAPTER 1

HOUSING NEEDS

Pakistan shares with most of the developing countries the traits of overpopulation, being one of the most densely populated areas in the world; paradoxically she also has one of the lowest per capita incomes. The financial resources of the individual or the government are far too inadequate to tackle the fast growing problem of housing. Squatters, ill-housed and unhoused today more than ever before, pose a challenge which if not realized early, apart from other humane considerations, is bound to have serious political implications.

The lack of information about building materials was one of the main hurdles in the way of an objective study of house building in Pakistan. A survey of building materials helped in deciding upon the future course of action.

1.1 HOUSING POLICY

Very little has been said or done about the gravity of housing conditions in the sub-continent before or after partition.[1] There is no doubt that the situation in urban areas is acute due to migration of

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1. Lack or non-existence of factual information about prevailing housing conditions in the country has so far prevented any realistic assessment of the housing needs. The following have, however, attempted in different ways to give an idea of the magnitude of the problem though in very vague terms.
   i) UNITED NATIONS, "Low cost Housing in South and South-East Asia", Report of the mission of experts (22 Nov. 1950 - 23 Jan. 1951), New York, 1951.
   ii) see next page.

the rural population to the towns in search of employment and due to various other reasons. But little or no attempt at all has been made to assess the housing conditions of about 90% of the population of the country that lives in rural or suburban areas.

The policy, if anything of the kind exists, about rural areas has been to leave it entirely to themselves to solve their shelter problem as best as they can with the only material at hand - the soil. The UN mission of experts which visited Pakistan in 1950, though it strongly advocated improvement in rural housing, yet expressed its inability to make any practicable recommendations in view of the magnitude and the nature of the problem.[1] This mission in fact did not go beyond a visit to a few selected sites.

A similar attitude can be traced in the report of 'The Health Survey and Development Committee' constituted by the then British government to look into the problems of urban and rural housing. This report, made public in 1946, also acknowledged that the rural areas presented the most difficult problem, but regretted that attention might have to be confined only to any new villages that might be established.[2]

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ii) UNITED NATIONS, "Housing in Tropical Areas", Town and Country Planning and Housing, Bulletin II and III.

iii) KOENIGSBERGER, O.H., "Indian Housing Problems", International Federation for Housing and Town Planning, News-sheet VIII, 1948.

iv) HEALTH SURVEY AND DEVELOPMENT COMMITTEE, "Survey and Recommendations", Government of British India, Delhi and Calcutta, 1946.

1. UNITED NATIONS, "Low cost Housing in South and South-East Asia", Report of the mission of experts (22 Nov. 1950 - 23 Jan. 1951), New York, 1951.

2. HEALTH SURVEY AND DEVELOPMENT COMMITTEE, "Recommendations", Vol.II, Delhi and Calcutta, 1946 (pp.219-247).

Retreating a little further into the history of rural housing, one discovers some attempts at imposition of western concepts of planning when new areas were brought under irrigation in 1894 in the Panjab. Village sites were laid out with wide dusty streets with no other provisions of any kind. In an effort to provide more open planning, large plots for the construction of houses were given to the peasants. In most cases the owner, who could not afford to build and maintain more than a one- or two-room dwelling, was now compelled for the reasons of safety and privacy to build at least a wall around his plot. The physical consequences of this kind of approach are illustrated in the next chapter.

It was noticed that the incentive for the improvement in environment came, wherever it did, from the top instead of coming from below. The lead for reform in land use was not taken by any public or private institution; the authorities imposed it without necessary enquiries. No wonder this kind of approach showed little respect for social, economic and climatic conditions prevalent in the area.

Sir Patric Geddes stands out as an outstanding example amongst the foreigners who showed an understanding of the local traditions.[1] During his visit to the Indian sub-continent in 1914, his planning exhibition was sunk in the Bay of Bengal. He, however, reconstituted it and exhibited in Madras and Calcutta. He visited many areas and prepared half a dozen reports, though they were never executed. Although Patric Geddes' visit did not result in any tangible achievement, yet it was a stimulus to what was and remains the somewhat arid mechanical conception of land use planning in Pakistan today.

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1. GEDDES, A., "Patric Geddes in India", London, 1947.

Although no provision exists in The District Board Act to regulate the construction of houses in rural areas, detailed instructions regarding the selection of the village sites and the way in which villages are to be laid out have been given in Panjab Colony Manual.[1] Type plans have been prepared for mud houses of different kinds suitable for village construction but no evidence of these plans having been executed in practice could be found. Most of the villages have grown as and where they could without much outside control.

1.2 HOUSING REQUIREMENTS

1.2.1 Availability

The scope of the present study precludes an adequate description of the social and economic aspects of the prevailing housing conditions in the rural areas of West Pakistan. The condition of the dwelling can however generally be categorized according to the nature of the occupant's profession as follows.

a) The owner-farmer: Due to the security of the tenure the house would usually be reasonably built and maintained. Less overcrowding occurs in this category. Even in this case the house would be built on self-help basis though occasionally farm labour, if the farmer happens to have any, may also be deployed for lending a helping hand.

b) Full-time farmworker: He would normally live in a tied house built by himself on land owner by the farmer. Farm help is usually employed on a yearly basis. Due to uncertainty of the tenure, the dwelling is more often than not ill-kept.

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1. GOVERNMENT OF BRITISH INDIA, "Panjab Colony Manual", Government Printing Press, 1910.

c) Seasonal farmworker: This type of worker is usually migratory. He is employed during certain periods of the year when workload on the farm is heavy, for instance during harvesting. For the remainder of the year he engages himself in different occupations as and where the need for it arises. He generally squats on the open areas in or around the village. His dwelling is a temporary shack or tent, home-made from hides and skins of animals.

d) Non-agriculturists: They include shoemakers, carpenters, barbers, weavers etc. In most cases these tradesmen make villages almost completely self-sufficient communities. These people generally are an integral part and permanent residents of the village. Usually they are able to build their own one- or two-room dwellings on unoccupied pieces of land. In cases where the nature of the occupant is migratory, he has to look towards some farmer to be allowed to put up some kind of shelter on his land. It is usually an ill-built makeshift kind of structure. He may sometimes even be permitted the use of a dwelling vacated by some farmworker who has changed his employer. In these circumstances he would, however, be under some obligation to return occasional favours to his landlord in the form of running errands or rendering help at home or on the farm in an emergency. No rental system is operative in any of these categories.[1]

An overall picture of the available rural housing in the country at the time of the 1961 census is presented by Table 1 and 2.[2]

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1. For a discussion of economic factors in rural areas in general, see UNITED NATIONS, "Economics of Rural Housing", Housing and Town and Country Planning, Bulletin VI.

2. These tables are based on data obtained from GOVERNMENT OF PAKISTAN, "1961 Census", Government Printing Press, 1961.

TABLE 1. RURAL HOUSING

	Private households		Dwellings			Occupied Dwellings			
	No. (thousands)	Average size (persons/ household)	Total number	Number occupied	Average size (rooms/ dwelling)	Percent of dwellings with			
						1-2 rooms	3-4 rooms	5-6 rooms	7+ rooms
Rural	14,644	5.4	15,330	14,562	1.7	82.7	14.6	2.2	0.5
Urban	2,118	5.6	2,186	1,997	1.8	81.2	14.1	3.1	1.5
Total	16,762	5.4	17,516	16,560	1.7	82.5	14.5	2.3	0.7

TABLE 2. RURAL HOUSING

	Occupied dwellings				
	Average density (persons/room)	Percent of dwellings with persons/room			
		Less than 1.5	1.5 or more	2.0 or more	3.0 or more
Rural	3.1	10.3	89.7	84.1	60.7
Urban	3.1	14.6	85.4	80.4	59.0
Total	3.1	10.9	89.1	83.7	60.5

It may be noticed that no information about the piped water, bath, toilet, drainage etc. is provided in the 1961 census for the simple reason that these provisions do not exist in the case of rural housing.

1.2.2 Obsolescence

Housing in the rural areas is deteriorating very rapidly. Of the many reasons for this, the following may be regarded as the more important ones, though they are all inter-related.

a) Economic: Agriculture mostly is at subsistence level. It perhaps has always been, but the village communities which previously were self-contained as regards their primary needs, have gradually been subjected to outside economic pressures. The simple, though from western standards primitive, pattern of economy based on exchange of goods has cracked, giving rise to the pressure to earn cash to procure basic necessities. The farmer is consequently under constantly mounting pressure to grow more cash crops. This leaves him with little or no time to attend to the maintenance of his dwelling.

b) Technological: The art of earth construction in rural areas had been a highly developed one in earlier times when man had not yet become a specialist too much engrossed in his own particular field. A farmer or a hunter also built his own home in his spare time. Under the stress of the present-day circumstances a farmer cannot think of doing much else except farming. He has, therefore, gradually lost that skill and art of building in earth. When faced with an unavoidable situation of erecting a shelter for himself, he naturally tends to use short-cut methods like replacing a dome with a flat roof. This technique, ill suited to the inherent weakness of this material in tension, would have obvious consequences.

c) Demographic: The population of the rural areas as well as that of the country is increasing at an alarming rate as shown in Table 3.[1]

TABLE 3. RURAL POPULATION PROJECTIONS

	Population 1961 (Thousands)	Projected population 1975	Projected increase over 1961	Rate of increase (percent)
Rural	80,599	108,778	28,169	2.2
Total	93,720	126,475	32,755	2.1

As the rural population increases the landholdings become smaller and at one point uneconomical. The farmworker is then forced to migrate (or commute if feasible) to larger towns to work for his living. Due to the near impossibility of renting or buying a house in the town, he leaves his family in the village and himself huddles together with others like him in a one-room tenement in or around the town. This phenomenon has little influence on the general pattern of the growth of rural population as represented by Table 3. It, however, has a serious effect on availability and condition of housing in the rural areas. The absence of the working members of the family for prolonged periods is directly reflected in the state of maintenance of the dwelling.

d) Climatic: The annual rainfall in the West Pakistan plains is far from heavy but it occurs in a few months (sometimes in a few weeks) and in

1. UNITED NATIONS, "Statistical Year Book 1964", Statistical Office, New York, 1964.

2. See Chapter 2.

the form of a few heavy downpours. The maximum rainfall in 24 hours can sometimes be as much as 10 inches which may well be the annual figure.[1] The results of this on earth houses, as seen in Chapter 2, may be serious if mud plaster is not renewed every year before the 'Monsoons'. The consistency in the repair of earth structures required by seasonal rains puts a heavy demand on the available human resources, so badly needed for agricultural purposes.

All these factors, taken together with many other sociological and psychological reasons, have set in a rapid obsolescence cycle. The obsolescence of the existing stock on the one hand, and the increase in rural population on the other hand, is widening the gap between supply and demand at an equally high pace.

1.3 PHYSICAL RESOURCES

An assessment of the available resources in men, money and materials is carried out in this section. The purpose is to find out how far these resources are capable of meeting the housing situation described in the previous section.

1.3.1 Finance

Housebuilding is beyond the resources of not only the common man but also of the middle class. The income of a farmer or man in the street is barely enough to meet his other fundamental necessities like food, clothing etc. Private developers do not exist for the same reason. House building is a privilege for the few who invariably waste large sums of money on whimsical grounds. The end products are ill-planned eyesores with a pathetic misuse of materials and resources.

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1. See REFERENCE MAP 2 : A, Part IV.

A 'House Building Finance Corporation' was established in 1952 with the objective of providing loans to prospective house builders. The results would not have been difficult to imagine even at the time of its inception. Only the richer class has been able to make use of this facility due to high rates of interest and huge costs involved in building a house under the circumstances. No evidence could be traced of loans from this source being obtained by the rural population.

No equivalent of what is known in the west as 'council housing' exists even in urban areas of Pakistan. The main reasons for this are: inadequate national resources, low priority to housing in the allocation of the available resources and misuse of the finances intended for 'Housing and Settlement'.

As a result of persistent dispute with India over Kashmir, Pakistan has to spend about 70% of her national budget on defence. This represents her efforts to forestall an ever widening gap between herself and India who, with resources six times larger, spends 60% of them on this account. This is no place to discuss political issues but these figures do present a glimpse of the tragedy which ultimately makes itself felt in added misery of the common man in his dilapidated 'home' - if home it must be called.

A look at the second and third Five Year Plan, representing a decade of national expenditure, may impress a casual observer due to the fact that a sizeable allocation of resources seems to have been made to what is described as 'Housing and Settlement' or 'Physical Planning and Housing'.[1,2] An analysis of the actual expenditure under these heads reveals quite a different story. Most of the money allocated to this sector went towards building an extravagant show-piece capital.[3]

1. GOVERNMENT OF PAKISTAN, "Second Five Year Plan", Government Printing Press, 1962.

2. GOVERNMENT OF PAKISTAN, "Third Five Year Plan", Government Printing Press, 1965.

3. See Plates 1-6 for some examples of 'low-cost housing' in the new capital.

TABLE 4. FINANCIAL RESOURCES
SECOND 'FIVE YEAR PLAN' ALLOCATIONS 1960-65

(excluding Defence)

(million Rupees)
(20 Rupees = £1)

Name of sector	Public sector	Semi-public sector		Private sector	Grand total
		Contribution from Govt.	Private investment and loans		
1. Agriculture	2,515	-	-	905	3,420
2. Water and power	4,140	-	190	60	4,390
3. Industry	100	1,360	575	3,085	5,120
4. Fuel and minerals	179	271	-	550	1,000
5. Transport and communications	2,612	113	420	905	4,050
6. Housing and settlement	1,410	475	390	1,135	3,410
7. Education and training	955	-	-	100	1,055
8. Health	370	-	-	50	420
9. Social services	85	-	-	15	100
10. Manpower and employment	35	-	-	-	35
	12,401	2,219	1,575	6,805	2,300
	14,620 Govt. financed		8,380 private financed		
	23,000				

TABLE 5

FINANCIAL RESOURCES

THIRD 'FIVE YEAR PLAN' ALLOCATIONS 1965-1970

(excluding Defence)

(million Rupees)
(20 Rupees = £1)

Name of sector	Public sector	Private sector	Total	% increase over 2nd Five Year Plan
1. Agriculture	4,340	2,000	6,340	116
2. Water and power	8,630	300	8,930	93
3. Industry	4,750	8,300	13,050	125
4. Fuel and minerals	900	750	1,650	92
5. Transport and communications	5,870	3,100	8,970	102
6. Education	2,740	300	3,040	181
7. Health	1,180	40	1,220	133
8. Manpower and social welfare	350	60	410	412
9. Works programme	2,500	-	2,500	213
10. Physical planning and housing	2,740	3,150	5,890	53
TOTAL	34,000	18,000	52,000	108

1.3.2 Manpower

This is perhaps the most abundant of the resources available in the country requiring an effective utilization both at the individual and the national level. A large percentage of the total working population is, in one way or another, dependent for their livelihood on agriculture as shown by Table 6.[1]

In the last column are also included the village tradesmen together with the rest of the working population. These tradesmen, though not directly connected with agriculture, are together with other working force a potential manpower which might be tapped for building homes for themselves or for others. A cheap durable material which did not require recurrent maintenance would in itself be a major incentive in this sphere.

TABLE 6. MANPOWER

(Thousands)

	Working population (15-64)	Rural working population		Non agriculturists
		Owner cultivators	Other agriculturists	
Total	30,206	21,796	646	7,764
Percent of total	100	72.16	2.14	25.70

1. GOVERNMENT OF PAKISTAN, "1961 Census", Government Printing Press, 1961.

1.3.3 Materials

Search for an optimum material led the author into an assessment of the availability and the cost of existing building materials. Lack of objective information in this field necessitated a short survey of the important materials used for housebuilding in a selected area.[1] A region comprising the new federal area was chosen for this purpose. Some of the reasons for this choice are as follows. First, this region on account of its geological situation contains almost all types of natural material in use in the rest of the country. A survey of this comparatively small area therefore provided information about a large number of materials. Second, the means of transportation in this area are better than any other region. These materials should therefore be more readily available in this area in comparison with the rest of the country. Third, due to the building of the new capital the demand is concentrated in a much smaller area, thereby having a favourable effect on the cost of these materials. Fourth, the distances between the sources of the supply of these materials and the consumption area are smaller as compared with other regions. This means lower cost for the transportation of the materials.

Inspite of all the above mentioned advantages if the materials are scarce and cost far beyond the means of the common man in this region the picture is least likely to be any brighter in the rest of the country. A brief discussion of each material in the light of the findings of this survey is given below.

1.3.3.1 Burnt Brick. Clay bricks are burnt in open kilns set up in the fields as close as possible to the area of consumption and transportation

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1. This information was gathered through the cooperation of a group of students of the University of Engineering and Technology, Lahore.

routes.[1] Suitability of the soil for the manufacture of bricks is determined by rule of thumb methods, such as visual inspection of the soil or the existence of a kiln nearby. The Capital Development Authority has however investigated some sites for setting up more brick kilns to meet the growing demand in the area.[2] The location of the recommended sites is shown on the accompanying map.

Burnt brick has often been suggested as an 'optimum' material even for rural housing without going any deeper into the implications of such a move.[3] Even in larger towns (with adequate facilities of transportation and concentration of demand) brick, though relatively cheap as compared with other materials, is far beyond the reach of the common man. Other factors apart, the possibility of setting up brick kilns in the rural areas with extremely poor means of transportation is far from being a practicable proposition. Inspite of heavy odds some better off villagers manage to import bricks from considerable distances to construct a room or two for themselves.[4] Such examples are very rare but they do represent desperate attempts to get rid of the necessity for vigilant maintenance, associated with earth dwellings, whatever the cost.

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1. See Table 7 and Fig.1 showing location of the brick kilns.

2. The Capital Development Authority is the controlling authority for the planning, building and civil administration in the new capital.

3. UNITED NATIONS, "Low cost Housing in South and South-East Asia", Report of the mission of experts, New York, 1951.

4. See Plate 50 in 'Earth Housing,' Chapter 2.

A prior investigation of the soil to be used and scientific production of the bricks should no doubt result in greater economies and improvement in the technical properties of this material. However, no amount of production efficiency can bring the cost of this material within the means of the overwhelming majority of the population that lives barely above the subsistence level.

<u>1.3.3.2 Building Stone</u>. Stone is the primary material for building homes for the people living in the foothills of the Himalayas which range from the north to the north-west of the Indus Plains. Small quantities needed by these people for their extremely modest dwellings are found locally. Primitive methods requiring considerable labour are employed for quarrying this stone.

The commercial exploitation of this material in the federal area is carried out on a very limited scale due to high costs of quarrying and transportation. The quality of the stone within reasonable distances is also not of very high standard. This explains why its use is restricted to some luxury homes - mostly for decorative purposes.

Use of this material for low cost dwellings seems far from feasible even in the federal area. In the Plains it is not found in any appreciable quantities to make such a proposition worthy of serious consideration.[1]

<u>1.3.3.3 Cement Blocks</u>. Use of cement blocks has also begun in recent years in some areas as a substitute for burnt brick particularly where greater speed in construction and thermal properties are the main consideration. Commercial production of cement blocks exists on a very limited scale because of low demand. The isolated cases where their use is

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1. See Table 8 and Fig.2.

resorted to usually manufacture them on the site.[1] A reliable estimate of the cost of the final product could not be obtained because block-making on the site was not a self-contained or continuous operation. Labour, material and equipment used for the manufacture of blocks was part of the total constructional operation. It was acknowledged by some small contractors, having experience of both brick and block construction, that there was no appreciable difference in the overall cost of the dwelling. Small economies achieved due to accelerated speed in construction are balanced by the added cost due to large quantities of cement and sand required for the manufacture of these blocks.

<u>1.3.3.4 Sand</u>. River beds are the usual source of sand needed for building purposes. The situation of the federal area is favourable in this respect as well because a large number of small rivers and 'nullahs' flow through it.[2] On entering the plains from the hilly region they get slowed down and deposit good quality sand in their beds.[3] Most of the Indus Basin is not as fortunate because the large, slow moving rivers by the time they reach the heartland, have few sand particles left in them to deposit. Their beds therefore contain mostly deposited particles of fine clay. Use of sand in building low-cost houses in the Indus Basin, therefore, needs to be kept to the barest minimum.

<u>1.3.3.5 Aggregate</u>. The federal area has fairly large quantities of this material but the final cost after quarrying, crushing and transpor-

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1. No data about cement blocks was available due to this reason.
2. 'Nullah' is the local name for stream.
3. See Table 9 and Fig.2

tation to construction sites become prohibitive.[1] The possibility of developments in building techniques on the lines of 'NO fines' based on large scale exploitation of this material in the federal area is not ruled out.[2] Potential sources for aggregate in the Indus Plains are however so limited and far apart that in the Plains at least there seems little possibility of the success of a building technique based on any appreciable use of this material.

<u>1.3.3.6 Lime</u>. A direct use of lime is for whitewashing purposes but it also finds its way into the building industry in many other forms. A very significant use of limestone is in the manufacture of Portland cement. Large quantities of limestone are found in the North-western region apart from other places in West Pakistan where cement works have been set up. There appears to be considerable scope for the exploitation of these deposits for increasing cement output. Quicklime for use in the building industry is produced by burning limestone in kilns.[3] The use of lime for soil stabilization independently or in conjunction with Portland cement may bring about greater economies and improvements in the properties of stabilized earth.

<u>1.3.3.7 Cement</u>. As a binding agent Portland cement has revolutionized the building industry throughout the world. Some advanced countries are actively investigating certain other alternatives but it will be quite some time before the conditions in Pakistan are ripe enough for such a

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1. See Table 10 and 11 and Fig.2.
2. No fines is a technique developed by a British firm, WIMPEY, for building low-cost homes.
3. See Table 12.

change to be feasible.[1] The presence of large limestone resources as basic raw material and recent discoveries of natural gas deposits at Sui as fuel, forecast a happy future for this vital building material industry.[2]

1.3.3.8 Steel. Pakistan is heavily dependant on imports for her steel requirements. Some deposits of iron ore were discovered at Kalabagh some years ago but a decision about the feasibility of setting up a steel plant based on this raw material has not so far been reached. A promise of Russian cooperation has recently given a new incentive to the project and another feasibility study is under way. Serious shortage of steel in Pakistan would remain even after the completion of this plant. Maximum economy in the use of steel in low-cost housing would have to be aimed at.[3]

1.3.3.9 Timber. The position of this material as regards availability and cost is not better than the rest of the important building materials. Forests constitute only about 2 percent of the area of the country. Most of these forests lie in the remote areas with no means of transportation. The foothills of the Himalayas are the only source of timber in West Pakistan but the resources are far too inadequate.[4] Some inferior

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1. Various types of industrial wastes, emulsions, resins and chemicals are being tried as a substitute or to supplement the functions of the Portland cement.
2. See Table 13.
3. Industries listed in Table 14 are not steel manufacturing plants but merely re-rolling foundries producing items like mild steel bars for reinforcement purposes.
4. See Tables 15-19.

varieties of timber like 'Sheesham' are grown by the farmers for their needs on the boundaries of their fields or in the villages.[1] These local varieties are very hard and difficult to work. Their present use by the villagers is in a very unsophisticated manner. The main trunk of a tree is used as a main beam and smaller trunks as secondary beams and battens.[2] Joinery is kept crude and simple in detail.[3] It is quite apparent that for any future house building in this region the local resources of timber would have to be relied upon. The requirements of each farmer, as at present, may be met without much difficulty from the trees that he grows in his fields. In some areas incentive to the peasants for growing more trees would need to be provided in an objective and planned manner.

This very brief appraisal only tries to show that housing demand in rural and suburban areas is critical and that the present high costs and scarcity of building materials are the main hurdle in the way of an individual building a home for himself for which he has a crying need, a cherished longing and the needed manpower. Under the circumstances a viable approach towards making a house an accessible commodity seems to be in bringing about a significant reduction in the cost of the main material. Appreciation of this hard fact initiates a fresh inquiry into the oldest material of construction which inspite of its shortcomings is still the only available material for 86% of the population.

> "It is good for the mind to go back to the beginning because the beginning of any established activity of man is its most wonderful moment. For in it lies all its spirit and resourcefulness from which we must constantly draw our inspirations of present needs." (Louis I. Kahn)

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1. 'Sheesham' is the local name for Dalbergia Sissoo.
2. See Plate 33 and 48, in Chapter 2.
3. See Plate 49 in Chapter 2.

PLATE 1.

A general view of the low-cost housing area in the new capital.

PLATE 2.

A street scene of the housing for the lowest class of central government employees. Notice the vaulted 'double-roofs' to boost the architectural appearance.

PLATE 3.

A rather rare example of successful environmental treatment of the alley, but with inadequate provision for private enclosed space.

PLATE 4.

An application of western ideas of terraced housing.

PLATE 5.

Imposition of space standards unsympathetic to the inhabitants' social structure and habits.

PLATE 6.

Massing of concrete and bricks with what results, at what cost and for how many?

FIG: I BRICK KILNS IN THE FEDERAL AREA

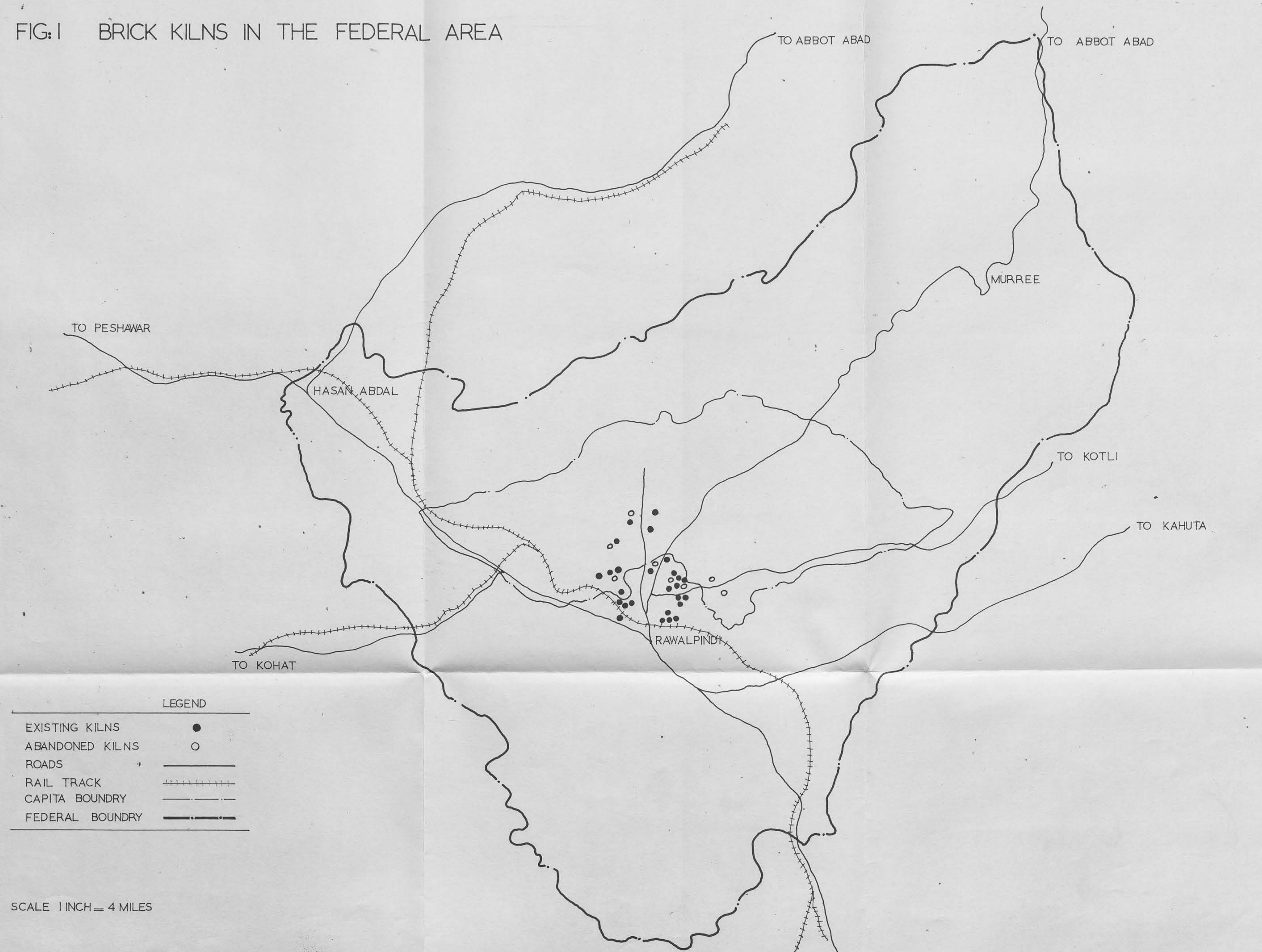


TABLE 7

SURVEY OF EXISTING BRICK KILNS IN THE AREA

S. No.	Owner/ Description of kiln	Location	Present condition	Daily outturn	Kiln capacity in one round	Age of kiln
1	2	3	4	5	6	7
1.	Ch. Leaqat Ali.	M/4/6 Saidpur Rd.	Running.	10,000 Nos.	4,00,000	3 Years.
2.	P.W.D.	M/4/6 " "	Abandoned.	-	4,00,000	3 "
3.	Ch. M. Yousaf.	M6/4 " "	Restarted.	10,000 Nos.	3,00,000	4 "
4.	Raja Alladad	M6/7 " "	Stopped.	10,000 "	4,00,000	3½ "
5.	Raja Zafar.	M7/0 " "	Restarted.	10,000 "	3,50,000	3 "
6.	P.W.D.	M5/1 " " off ½ mile left.	Abandoned.	-	3,00,000	5 "
7.	P.W.D.	-do-	-do-	-do-	-do-	-do-
8.	P.W.D.	-do-	-do-	-do-	-do-	-do-
9.	Ch. Abdul Jabbar.	M5/3 Lehtrar Rd.	Running.	15,000 Nos.	4,00,000	3 Years.
10.	Raja Yousaf.	-do-	-do-	10,000 "	35,000	3 "
11.	Private owner.	-do- ½ mile off left.	-do-	10,000 "	4,00,000	2 "
12.	-do-	M5/3 Lehtrar Rd. 1 mile off to left.	-do-	10,000 "	4,00,000	2 "

1	2	3	4	5	6	7
13.	Private owner.	M5/2 Lehtrar Rd. 1½ miles off left.	Running.	10,000 Nos.	4,00,000	3 Years.
14.	-do-	M5/3 Lehtrar Rd.	-do-	10,000 "	4,00,000	4 "
15.	Ch. Noor Mohd.	M5/4 Lehtrar Rd.	-do-	10,000 "	4,00,000	5 "
16.	Ch. Karamdad.	M5/6 Lehtrar Rd.	-do-	10,000 "	2,00,000	2½ "
17.	Mirza Abdul Malik.	M5/7 Lehtrar Rd.	-do-	10,000 "	3,50,000	3 "
18.	Private kilns.	M4/3 Murree Rd.	Abandoned.	-	-	-
19.	Abdul Rehman.	M5/6 Murree Rd.	Running.	10,000 "	4,00,000	3½ "

Abbreviations used:

P.W.D. = Public Works Department.

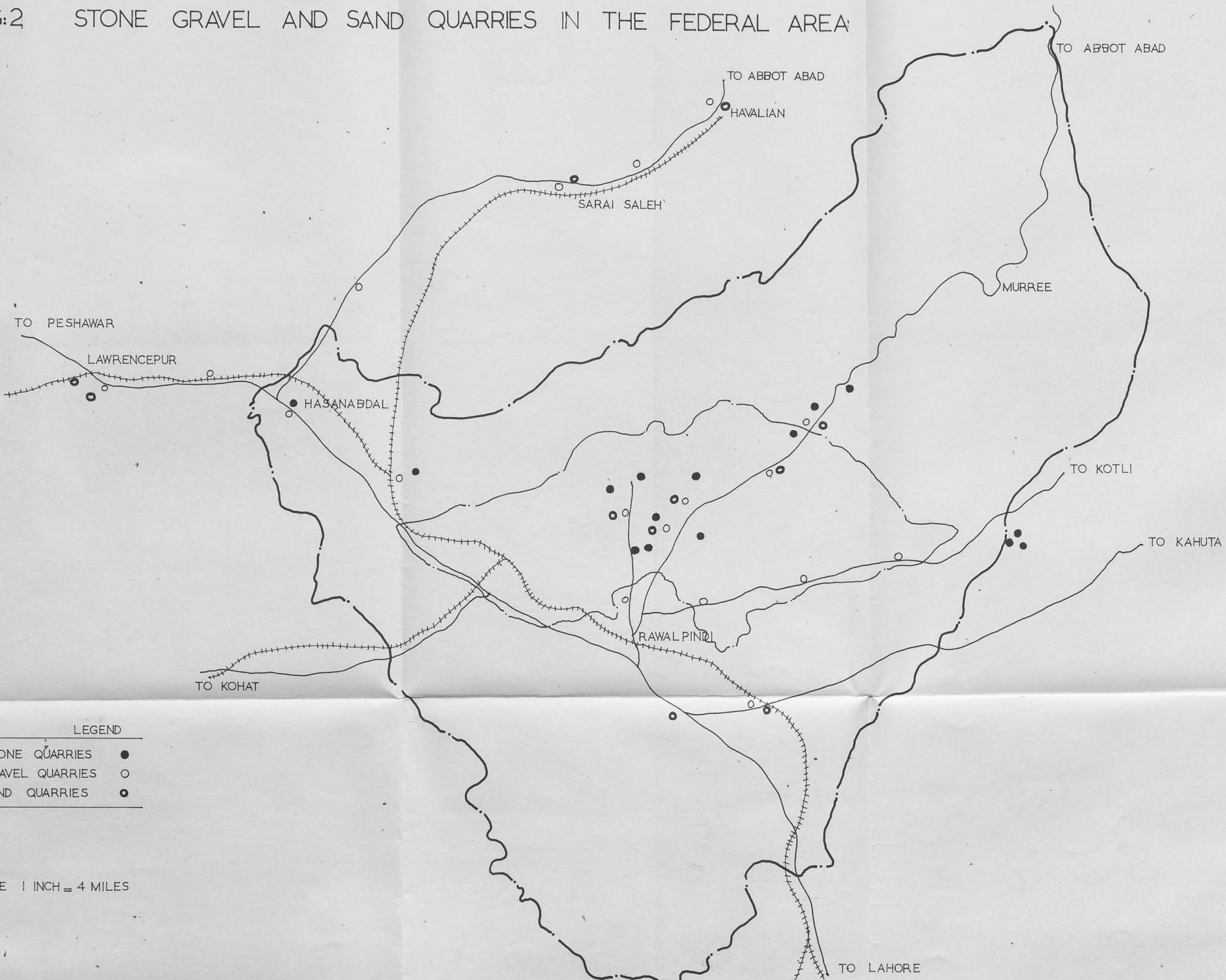
M4/3 Murree Road = At a distance of 4 miles and 3 furlongs from Rawalpindi on Murree Road.

TABLE 8

SURVEY OF STONE QUARRIES IN THE AREA

S. No.	Quarry site of source	Physical Characteristics				Place where already used
		Quality	Colour	Percentage of water absorption	Present quarrying rate per % c.ft. at quarry site	
1	2	3	4	5	6	7
1.	Mile 24 of Murree Road near Salagran bridge.	Hard sand	Grey	2.8	Rs.20/-	Retaining walls of Murree Road.
2.	Miles number 15 to 17 of Murree Road.	-do-	Cement colour.	3.9	30/-	Villages near the site.
2A.	-do-	-do-	Grey	1.9	20/-	-do-
2B.	-do-	-do-	Reddish	2.8	20/-	-do-
3.	Mile number 13/4 Nurpur Road.	-do-	Light Grey Reddish.	1.7	20/-	Nurpur and surroundings.
4.	Saidpur hills.	Very hard sandstone.	Yellow.	-	Not quarrying.	-
5.	Saidpur hills.	-do-	Dark Grey.	4.7	20/- to 24/-	Saidpur.
6.	Shakkar Parian hills.	Hard sandstone.	Light Grey.	3.7	20/-	Shakkar Parian.
6A.	-do-	Slate-like stone not fit for construction.	Reddish.	1.7	20/-	-do-

FIG: 2 STONE GRAVEL AND SAND QUARRIES IN THE FEDERAL AREA



LEGEND

STONE QUARRIES ●
GRAVEL QUARRIES ○
SAND QUARRIES o

SCALE 1 INCH = 4 MILES

1	2	3	4	5	6	7
7.	Mile number 24 of Lehtrar road.	Hard sandstone.	Cement colour.	4.1	20/-	Surrounding villages.
8.	Mile number 21 of Lehtrar road.	-do-	Grey.	1.9	20/-	-do-
9.	Kattarian village along	Porous not fit for construction.	Light Reddish.	5.9	20/-	Kattarain and surroundings.
10.	Rawal hills.	Hard sandstone.	Reddish Grey.	2.3	20/-	Surroundings.

TABLE 9 SURVEY OF SAND QUARRIES IN THE AREA

S. No.	Location	Description	Rate at quarry site per 100 c.ft.	Rate at loading station, loaded into Railway wagons, per 100 c.ft.	Rate at Rate including carriage by Trucks, per 100 c.ft.
1	2	3	4	5	6
1.	Lawrencepur.	Coarse sand.	Rs. 5/-/-	Rs. 25/-/-	Rs. 50/-
2.	Haro River on G.T.road, near Burhan.	Fine sand.	Rs. 10/-/-	Rs. 30/-/-	Rs. 55/-
3.	Sarai Saleh.	Coarse sand.	Rs. 20/- (per truck)	-	Rs. 65/-
4.	Soan River bed along G.T. road.	Medium coarse sand.	-	-	Rs. 20/-

TABLE 10. SURVEY OF AGGREGATE QUARRIES IN THE AREA*

S. No.	Description of material	Location	Percentage of different size of aggregate						Quality	Approximate cost of quarrying at source per 100 c.ft.
			Sand		Bajri (Stone Aggregate)					
			Fine sand	Coarse sand	$\frac{1}{4}$" to $\frac{1}{2}$"	$\frac{1}{2}$" to 1"	1" to 2"	Above 2"		
1	2	3	4	5	6	7	8	9	10	11
1.	Sand and Bajri.	Sangran Bridge. Murree Road.	-	5	5	10	40	40	Hard round but not properly graded.	Rs. 16/- to 20/-
2.	-do-	Chatter Bridge Murree Road.	5	-	20	20	40	20	-do-	Rs. 16/- to 20/-
3.	-do-	Barakow miles number 13 & 14 Murree Road.	5	-	25	30	30	15	-do-	Rs. 16/- to 20/-
4.	-do-	Mile number 15 Nurpur road.	-	5	10	20	35	25	-do-	Rs. 15/- to 20/-
5.	-do-	Saidpur mile number 8/4.	10	-	5	15	30	30	-do-	Rs. 15/- to 20/-
6.	-do-	Leh Nullah near Holy Family Hospital.	10	5-10	60	10	10	-	Hard round properly graded.	Rs. 10/-

* Accessible by road only.

1	2	3	4	5	6	7	8	9	10	11
7.	Sand and Bajri.	Soan river mile number 18 of Lehtrar Road.	10	-	10	10	20	50	Hard round but not properly graded.	Rs. 15/-
8.	-do-	Gumrah Nullah mile number 6 & 7 Lehtrar Road.	50	10 Clay	10	10	-	20	-do-	Rs. 15/-
9.	-do-	Korung river mile number 6 Lehtrar road.	10	5	10	30	20	25	-do-	Rs. 25/- to 35/-
10.	-do-	Soan river G.T. road.	50-60	-	5	10	20	20	-do-	Rs. 15/-
11.	-do-	Kattarian Nullah near Kattarian village Nurpur road.	5	10	20	10	20	35	-do-	Rs. 15/-

TABLE 11 SURVEY OF AGGREGATE QUARRIES IN THE AREA*

S. No.	Description of material	Quality	Location of Quarry	Size of material	Cost analysis per 100 c.ft.			Distance from Rawalpindi
					Cost of quarrying & stacking at quarry site	Name and distance to the nearest Railway station	Rate F.O.R. at loading station	
1	2	3	4	5	6	7	8	9
1.	Bajri.	Hard round and properly graded.	Chablat Nullah near Hasanabdal.	1/8"-3/8" 1/4"-3/4"	10/-/-	3½ miles Hasanabdal.	40/- 34/8/-	31 miles. 31 miles.
2.	-do-	-do-	Haro river on G.T. road.	1/8"-3/8" 1/4"-3/4"	10/-/- 6/-/-	3¾ miles Burhan.	40/- 33/8/-	36 miles. 36 miles.
3.	-do-	-do-	Turnawa on Taxila Haripur road.	1/8"-3/4"	20/-/-	8 miles Taxila.	36/-	26 miles.
4.	-do-	-do-	Usman Khattar.	1/8"-3/4"	15/-	1 mile Usman Khattar.	32/-	17 miles.
5.	-do-	-do-	Haro river on Hazara road.	1/8"-3/8" 1/4"-3/4"	12/-/- 8/-/-	6 miles Hasanabdal.	42/- 34/-	36 miles.
6.	-do-	-do-	Chaharikass on Hazara road.	1/8"-3/4" 1/8"-3/4"	10/-/- 10/-/-	9 miles Hasanabdal.	-	40 miles.

* Accessible by road and rail.

1	2	3	4	5	6	7	8	9
7.	Bajri.	Hard round but not properly graded.	Sarai Saleh.	1/8"-3/4"	13/-	1 mile Sarai.	22/-	65 miles.
8.	-do-	-do-	Beldher.	1/8"-3/4"	12/-	-do-	22/8/-	70 miles.
9.	-do-	-do-	Havellain.	1/8"-3/4"	10/-/-	-do-	23/-/-	80 miles.

TABLE 12 SURVEY OF LIME KILNS IN THE AREA

S. No.	Name of Owners	Location	No. of kiln	Size of kiln	Source of lime stone	Fuel	Daily Output
1.	Ch. Muhabbat Khan.	Railway Workshop Road.	1	700 to 1000 Mds.	Saidpur	Cinder	50 to 80 Mds.
2.	Khair Mohammad.	-do-	2	300 to 700 Mds.	-do-	-do-	60 to 90 Mds.
3.	M. Yousaf and M. Hussan.	-do-	3	-do-	Noorpur	-do-	100 Mds.
4.	Ghulam Mohammad, Khalilur-Rehman & Abdul Karim.	-do-	3	-do-	-do-	-do-	100 to 150 Mds.
5.	Mian Ahmad Din and Nazir Ahmad.	-do-	2	-do-	-do-	-do-	-do-
6.	Haji Ibrahim.	-do-	3	-do-	Rawal.	-do-	-do-
7.	Ghulam Haider	-do-	2	-do-	-do-	-do-	-do-
8.	Mazhar Hussan.	-do-	3	-do-	Barakohu.	-do-	-do-
9.	Malik Mir Ahmad.	-do-	2	-do-	-do-	-do-	-do-
10.	Attock Oil Company.	Jarahi Morgha.	1	600 Mds.	Wah.	Gas.	100 Mds.

Rate per Maund (80 lbs) = Rs.3.

TABLE 13

SURVEY OF BUILDING MATERIALS INDUSTRIES

CEMENT

S. No.	Name of Industry	Description of articles manufactured	Present installed capacity, per day	Present actual output per day	Raw Material being used: Imported: Material	Raw Material being used: Imported: Value	Raw Material being used: Indigenous: Material	Raw Material being used: Indigenous: Value	Labour employed	Scope of expansion	Foreign exchange needed for expansion
1	2	3	4	5	6	7	8	9	10	11	12
			Tons	Tons		Rs.		Rs.			Rs.
1.	Zeal Pak Cement Factory, P.I.D.C., Hyderabad	Cement	815	210	Fuel oil, coal.	Not given.	Limestone clay Gypsum coal,	2,00,000	442	Can be increased 1½ times.	90,00,000
2.	A.C.C. Cement Works, Head Office McLeod Road, Karachi.		910	830		Not given.	latrite Sui Gas Gunny bags.	1,25,000	250	-do-	Not given.
3.	Dalmia Cement Ltd., Shantinagar, Karachi.		750	500		1,50,000		1,00,000	159	Can be doubled.	52,30,000
4.	Maple Leaf Cement Factory, Skandarabad, Daudkhail.		125	370		Not given.		1,30,000	250	Can be increased 1½ times.	83,00,000
5.	A.C. Works, Wah Rohri.		415	270		Not given.		1,00,000	164	-do-	Not given.
6.	Dalmia Cement Ltd., Dandot.		250	255		Not given.		1,25,000	174	-do-	1,00,000,000
7.	Asam Bengal Cement Co.Ltd., P.B.,Chattak(Sylhet)E.Pak.		165	65		Not given.		80,000	101	-do-	Not given.
	TOTALS		3430	3470		1,50,000		8,60,000	1540		3,25,30,000

TABLE 14

SURVEY OF BUILDING MATERIALS INDUSTRIES

STEEL

S. No.	Name of Industry	Description of articles manufactured	Present installed capacity per day	Present actual output per day	Raw material being used: Imported		Raw material being used: Indigenous		Labour employed	Scope of expansion	Foreign exchange needed for expansion
					Material	Value	Material	Value			
1	2	3	4	5	6	7	8	9	10	11	12
			Tons	Tons		Rs.		Rs.			Rs.
1.	The Batala Engineering Co.,Badami Bagh,Lahore.	M.S.Rod (round) Flat Bars.	240	200	M.S. Billets	Not given	-	-	500	Can be increased	Not given
2.	Ismailjee & Sons, Saddar, Rawalpindi	Square Bars M.S. Angles	50	50		50,000	-	-	80	-do-	60,000
3.	Farid Mohd Mohd Hussain, City Saddar Rd., Rawalpindi.	(of all sizes)	15	32		75,000	-	-	50	Can be doubled.	60,000
4.	Lahore Steel Re-rolling Mills, Badami Bagh,Lahore.		30	25		75,000	-	-	40	-do-	Not given
5.	Frontier Industries Ltd., Pull Pukhta, Peshawar.		15	15		75,000	-	-	90	Can be increased 4-5 times.	1,00,000
6.	Pakistan Steel Re-rolling Mills, Badami Bagh,Lahore.		10	8		70,000	-	-	40	Can be doubled.	60,000
7.	Karimi Industries Re-rolling Mills, Dilzak Rd., Peshawar.		48	30		4,00,000	-	-	40	Can be increased.	6,00,000
	TOTALS		408	360		8,45,000			840		8,20,000

TABLE 15. SOURCES OF TIMBER IN WEST PAKISTAN

S. No.	Species: Trade Name	Species: Scientific Name	Locality of Occurrence	Durability	Annual outturn c.ft.	Air-dry density lbs/c.ft.	Uses
1	2	3	4	5	6	7	8
1.	Chir.	*Pinus longifolia*	Murree Hills and Hazara District.	N.D.	1,254,080	38	A popular building timber, particularly for roofing, flooring, shingles, etc. It makes good railway sleepers after preservative treatment. Also suitable for transmission poles and for the manufacture of matches.
2.	Kail.	*Pinus excelsa*.	-do-	N.D.	165,850	32	A well known joinery wood suitable for constructional work, house fitments, light furniture, shingles, packing cases, cores of laminboards, drawing boards and plane-tables.
3.	Deodar.	*Cedrus deodara*.	Kaghan Valley.	D.	57,800	35	An important structural timber. It is suitable for railway sleepers, carriage and wagon work, house-building beams, floor-boards, door and window frames, light furniture, shingle ordnance boxes and pattern making.

1	2	3	4	5	6	7	8
4.	Shisham.	<u>Dalbergia sissoo</u>.	Irrigated plantations in Lahore and Multan Circles.	D.	442,400	50	Finest wood for furniture, cabinets and carving. A good constructional wood employed in house-building and general joinery and carpentry work. Extensively used for carts and carriages, agricultural implements and ordnance articles. An excellent fuel wood.
5.	Mulberry.	<u>Morus alba</u>.	-do-	M.D.	178,000	42	High quality wood for sports goods, such as hockey sticks, tennis, badminton and squash rackets. Also used for camp furniture, picker arms and carriage building. A moderate grade firewood.
6.	Babul.	<u>Acacia arabica</u>.	Hyderabad, Sukkur and Lahore Circles.	D.	591,000	52	Carts, agricultural implements, tool handles, tent pegs, pitprops. Excellent firewood. Fairly good turnery wood.

TABLE 16

SOURCES OF TIMBER IN EAST PAKISTAN

S. No.	Species: Trade Name	Species: Scientific Name	Locality of Occurrence	Dura-bility	Annual outturn: tons	Air-dry density lbs/c.ft.	Uses
1	2	3	4	5	6	7	8
1.	Sundri.	_Heritiera minor._	S Sunderbans.	D.	20,000	58-65	Constructional work, bridges, boat, carriage and cart building, shelves and toll handles, posts, poles and pitprops, agricultural implements.
2.	Passur.	_Carapa moluccensis._	-do-	F.D.	5,000	49	Furniture, cabinet making, house posts, tool handles and firewood.
3.	Sal.	_Shorea robbusta._	Dacca, Mymensingh and Dinajpur.	D.	42,000	50-56	Construction works, beams, rafters, flooring, bridges, railway carriage and wagon work, railway sleepers, carts, tool handles, poles, posts and piles.
4.	Koroi.	_Albizzia procera._	Chittagong, Cox's Bazar, Mymensingh and Sylhet.	M.D.	350	38	Constructional works, bridges, buildings, furniture and panelling.
5.	Chapalish	_Artocarpus Chaplasha._	Chittagong, Chittagong Hill Tracts, Cox's Bazar, Mymensingh, Sylhet.	D.	4,000	34	Light constructional work, furniture, boat and ship building, panelling and railway carriages.
6.	Jarul	_Lager-stroemia flosreginae_	Chittagong, Chittagong Hill Tracts, Cox's Bazar and Sylhet.	F.D.	2,250	37-40	Constructional work, house-building, carts, railway wagon work, boat and ship building, mill work, interior fitments, boot lasts.

1	2	3	4	5	6	7	8
7.	Gujran.	<u>Diptero-carpus</u>.	spp. Chittagong, Chittagong Hill Tracts, Cox's Bazar and Sylhet.	N.V.D.	30,000	42-48	Constructional work, house-building, railway sleepers and railway carriage construction, flooring.
8.	Toon.	<u>Cedrela toona</u>.	Chittagong, Chittatong Hill Tracts, Cox's Bazar and Sylhet.	F.D.	750	35	Furniture, panelling, plywood, cigar boxes, toys, carriage and boat-building.
9.	Chikrasi.	<u>Chukrasis tabularis</u>.	-do-	M.D.	350	40-42	Furniture and cabinet making, plywood, domestic construction and house-building.
10.	Gamar.	<u>Gmelina arborea</u>.	Chittagong, Chittagong Hill Tracts and Cox's Bazar.	M.D.	550	30	Furniture, panelling, plywood, boat-building, boxes, pattern making.
11.	Tali.	<u>Dichopsis polyantha</u>.	-do-	F.D. F.D.	1,250	40-43	Roof structures and wall battens, shingles, cheap furniture, masts and spars.
12.	Teak.	<u>Techtona grandis</u>.	Chittagong and Chittagong Hill Tracts.	D.	1,500	38-43	Furniture, railway wagons and carriages, doors, windows, ship-building.

Abbreviations: N.D. Not durable.
F.D. Fairly durable.
M.D. Moderately durable.
D. Durable.
V.D. Very durable.

TABLE 17

ANNUAL OUT-TURN OF TIMBER FROM AZAD KASHMIR

1.	Deodar.	6,00,000	c.ft.	(Logs)
		1,55,000	"	(Scantlings)
2.	Kail.	2,00,000	"	(Logs)
		2,65,000	"	(Scantlings)
3.	Chir.	2,20,000	"	(Scantlings)
4.	Fir.	6,00,000	"	(Logs)
		15,000	"	(Scantlings)

TABLE 18

PRODUCTION OF SOFTWOODS IN AREAS OUTSIDE STATE FORESTS

1. **Swat Forests:**

(i) Fir and Spruce	300,000 c.ft.	
(ii) Kail	100,000 "	
(iii) Deodar	100,000 "	
	500,000 "	(Dargai Market)

2. **Kalam Forests:**

(a) Utror Forest	100,000 c.ft.)	
(b) Gabrol "	70,000 ")	Deodar 80%, Kail 5%,
(c) Ushu "	40,000 ")	Fir and Spruce 15%.
	210,000 "	

3. No exploitation in Dir Forests, though they have the potentiality of supplying about 3 to 4 lakh c.ft. per year.

4. Chistral forests produce about 200,00 c.ft. per year. The extraction difficult due to the absence of an all-weather road. Transportation by river not feasible as the river Kabul has to pass through part of Afghan Territory before re-entering Pakistan area.

5. Tribal markets (1957)

Market	Deodar Rs.5/- to 8/-	Kail Rs.4/- to 7/-	Fir and Spruce Rs.3/- to 4/-	Total
Bannu	492	36	672	1,200
Tank	500	200	400	1,000
Thal	1,050	300	150	1,500
Parachinar	468	36.4	15.6	500
TOTAL:	2,510	472.4	1,237.6	4,220

TABLE 19

STATEMENT ON THE PHYSICAL AND MECHANICAL PROPERTIES AND USES OF ANDAMAN TIMBERS

S. No.	Species of wood	Air-dry Density: lbs/c.ft.	Strength properties compared to those of Teak Wood as 100					Characteristics, Uses and Substitutes
			Strength as a beam	Suitability as a post	Shock resisting ability	Shear	Hardness	
1	2	3	4	5	6	7	8	9
1.	Andaman Padauk (<u>Paterocarpus dalbergioides</u>)	45	100	105	100	115	130	A red coloured wood with interlocked grain and rather coarse texture. A strong and durable timber. Suitable for cabinets, furniture, decorative panelling and constructional work. A very good substitute of teak and shisham.
2.	Kokko (<u>Albizzia lebbek</u>).	40	85	90	85	125	100	It has a rich walnut brown colour and a fairly even texture. It is moderately durable in exposed locations, but durable for interior use. Excellent for high class furniture, interior decoration and panelling. A good substitute of teak, shisham and walnut for the above purposes.
3.	Chaplash (<u>Artocarpus Chaplasha</u>)	34	80	80	75	100	90	A moderately hard, yellowish-brown wood with even but coarse texture and good durability. Suitable for light constructional work, joinery and furniture. Fairly good substitute of teak and deodar.
4.	Lalchini (<u>Amoora wallichii</u>)	39	80	85	95	95	80	A reddish-brown wood with straight grain and medium texture, moderately hard and fairly durable. Suitable for general construction and furniture. A very good substitute for chir and kail.

1	2	3	4	5	6	7	8	9
5.	Chuglam (<u>Terminalia</u> spp)	26	D a t a N o t A v a i l a b l e					A yellow colour of rather coarse texture. It is not a durable timber. Suitable for packing cases in place of fir and spruce.
6.	Thingan (<u>Hopea Odorata</u>).	49	110	95	100	110	130	Yellowish-brown wood of fine even texture. A strong tough and durable wood. Suitable as a constructional timber in place of teak and sissoo.
7.	Pyinma (<u>Lagerstroemia hypoleuca</u>) (rather unusual sample)	53	D a t a N o t A v a i l a b l e					A reddish-brown wood of even, medium texture. A hard and heavy timber, fairly durable. Suitable for general constructional work in place of sissoo.
8.	Gurjan. Identity doubtful, appears to be <u>Lagerstroemia hypoleuca</u>.	45.6	80	75	85	100	80	Pale reddish-brown wood, straight grained and medium textured. A fairly durable and strong wood. An average quality timber suitable for general construction, interior fitments and joinery. Can be used in place of deodar and chir.
9.	Yamnin. Identified as <u>Zanthoxylum rehetsa</u>.	42	D a t a N o t A v a i l a b l e					A greyish-yellow wood of medium texture. Moderately hard, heavy and durable wood. A general utility wood recommended for joinery and cheap furniture in place of chir and kail.
10.	Red Dhup (<u>Canarium</u> spp)	34	50	55	55	70	40	A pinkish-grey wood, fairly durable under cover, but perishable in exposed locations. Suitable for packing cases in place of fir and spruce.
11.	Mahuwa (<u>Bassia latifolia</u>).	62	75	75	100	120	165	A very hard and heavy wood od dark red colour and good durability with straight grain and fine, even texture. Suitable as a constructional wood in place of sissoo, but not recommended for furniture.

1	2	3	4	5	6	7	8	9
12.	Badam. Identity doubtful. Appears to be *Diptero-carpus* spp.	44	D a t a N o t A v a i l a b l e					A reddish-brown wood, fairly straight grained, but coarse textured. It is a moderately hard and heavy wood, not durable in the open. It is a cheap constructional timber suitable for house building in place of chir.

CHAPTER 2

EARTH HOUSING

Earth has been used as a material of construction from time immemorial and down to the present day because of its ready availability and constructive qualities. A few selected examples from a fairly extensive survey of earth housing in many developing countries in general and West Pakistan in particular are presented in pictorial form mostly to speak for themselves about the causes that have led to the downfall of what was once an accomplished art.

2.1 EARTH AS BUILDING MATERIAL

Earth has been a principal building material throughout the ages and continues to be so in the rural and sub-urban areas of the developing countries. In order to investigate the underlying phenomenon in the gradual disrepute of this material a four month fact-finding trek took the author into the heartlands of many countries where earth is still the primary means of erecting a shelter.[1] Out of numerous, varied and interesting examples one at 'Alqurna' in Egypt is picked out for illustration.

2.1.1 Earth housing project at Alqurna (Egypt)

This project was initiated by the Egyptian government to rehouse the inhabitants of a whole village in planned environments and to try out some ideas of self-help housing. The main motive was to project this as a model village providing incentive for the villagers to follow

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1. Countries visited include Morocco, Algeria, Tunisia, Lybia, Egypt, Sudan, Saudi Arabia, Syria and Iraq.

the example. This example has been chosen because due to its special circumstances it occupies a significant position in the whole case for evaluation of the merits of earth housing. Its importance lies in the fact that the project had full government backing, and was designed and executed by a local architect who had considerable interest in earth housing. The villagers provided voluntary labour on a cooperative self-help basis. Everyone concerned with the project showed great enthusiasm. The project, true to its original intentions, was given wide publicity both in the country and outside.[1] Architects as well as laymen were excited due to considerable imagination visible in the forms and principles of structures.[2]

Basic constructional principles were simple: to use this material in compression only. Traditional forms like domes, arches and vaults were used with success. Constructional details were conceived in sympathy with the skill of the local craftsmen. Sun-dried adobe brick was used for all buildings. In some important community buildings one or two courses of stone were used to act as foundations and to protect against rising moisture.

All was well for the first two or three years after the completion, but soon after the trouble started. When the initial mud plastering wore off with the rains, villagers could not be persuaded to keep up the tempo of enthusiasm associated with first thoughts of owning well-built and healthy homes of their own. They had not quite appreciated the fact at the beginning that maintenance efforts for larger structures, using the same material, would be even greater than for their previous abodes.

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1. ARCHITECTURAL REVIEW, "A Model Village in Upper Egypt", by Hasan Fathy Bey, Sept.1947, pp.97-99.
2. MARKUS, T.A., "Design Techniques for Earth Housing", M.Arch. Thesis, M.I.T. (USA), 1955.

The results of insufficient attention to this aspect of earth housing soon began to show in a very spectacular manner. Penetration of rainwater, through apparently small cracks in neglected and worn-off mud surface coatings, started resulting in major structural failures and soon it was too late for some attempts later made to repair these buildings. Thus within a decade of its conception, this all-important exercise in 'revitalization' of earth housing was in complete ruins. The inhabitants gradually moved back to their original dilapidated abodes which inspite of all their deficiencies were easier to look after due to their small size and their less severe exposure to driving rains on account of close clustering.[1]

2.1.2 Earth housing in the Indus Plains

Earth has been a natural choice for the inhabitants of the vast plains of West Pakistan there being hardly any other alternative building material available in earlier times. The great Indus civilization perfected the art of earth construction to its ultimate heights. Earth structures as old as 3000 years belonging to this age have been discovered in these plains.[2] Ruins of their cities like Mohonjeodaro are fine examples of planning with a great deal of emphasis on the provision of adequate standards in accommodation and basic amenities.

Earth is still the only building material for the entire rural and most of the sub-urban population spread over the deltas of five great rivers of West Pakistan. Villages are laid out on large and flat pieces of land with very wide streets and huge plots. The cob method

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1. See Plates 7-24.

2. CYTRYN, S., "Soil Construction", The Weizmann Science Press of Israel, Jerusalem, 1957, p.59: see pp.59-68 for a historical account of earth building.

of construction is mostly used in which all male members of the family take part. The soil generally has a considerably uniform texture and colour up to a depth of 5-6 feet and is dug from as near the site as possible. For initial construction of dwellings, at the time of layout, sites from where the soil was to be used for the purpose were marked out outside each corner of the village. These pits have gradually grown larger and during the rainy season get filled up with water flowing into them from all over the village. The water used in the houses during the rest of the year also finds its own course in the streets and finally to these ponds. Water thus stored in these ponds is used as drinking water for the animals and for puddling earth for further constructional purposes.[1]

2.2 EARTH HOUSING AND CLIMATE

After a brief background description, it is intended to carry out an objective evaluation of earth housing in the area surveyed as regards its susceptibility to some important climatic factors.

2.2.1 Rainfall

Rainfall is by far the most obvious single element having direct influence on the durability of the earth structure. Considered alone the effect of rain may be in the form of swelling which is attributed to the additional water loosening the bond between the soil particles held in equilibrium by the already present adsorbed water.[2] As these

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1. See Plates 25-50.
2. In nature every clay particle carries a negative electric charge and the intensity of this charge depends on the mineralogical character of the particle. This negative charge attracts the positive (Hydrogen) ion of the water, arranging the water molecules near the surface of the particle in a definite pattern. This is known as adsorbed water and is believed to be in solid state; for further explanation see SOIL SCIENCE, "The condition of water in porous systems", by Winterkorn, H.F., 1956, pp.109-115.

adsorbed layers grow during the wetting of clay particles, the effective solid volume associated with each particle increases and if the layers are in contact with each other the growth of individual layers will be reflected in an increase in total volume of the soil structure. A repetition of this phenomenon of swelling followed each time by shrinkage associated with consequent drying out of additional moisture, results in disintegration of mud plasters or the structures themselves if they have no surface coating.

2.2.2 Winds

Another important influence of rainfall on the weathering of this material is in combination with winds. Experiments have shown that the amount of rain driven onto a wall is directly proportional to the product of the rainfall on the ground and the wind-speed during the rain.[1] If the windspeed during the periods of rainfall is not recorded separately the averages of annual rainfall and windspeed may be used to establish an index of driving rain which would be a measure of the likelihood of penetration of rain. Direction of the winds during rainfall (or the average annual direction) would indicate the wall surfaces likely to encounter most of the weathering effect of driving rain.

Effects of the above two factors in combination are noticeable in some of the photographs taken soon after a heavy rainfall which was accompanied by strong winds from the north. The total rainfall was recorded to be about 1½ inches over a period of about 1¼ hours that it lasted. There were no means available to measure the windspeed which, based on previous experience, was guessed to be around 55 mph. Wall

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1. BUILDING RESEARCH STATION, "An Index of Exposure to Driving Rain", Digest 23 (second series), 1962.

surfaces facing the direction of the wind were severely wetted whereas those lying in the opposite direction were hardly affected except due to faulty parapet design; as illustrated in Plate 41. A close look at Plate 47 also reveals this phenomenon.[1]

2.2.3 Temperature

A well-known effect of temperature variations in the case of other building materials, in the form of shrinkage and expansion, is also felt by earth structures; but important in this case is also their role in causing sub-soil moisture movement from one region of the soil to another. These moisture movements take place in vapour form, through air spaces inside the soils having low moisture contents and are due to differences in the Relative Humidity of the water vapour in different parts of the soil.[2] Differences in Relative Humidity of water vapour are associated with variations in soil type, soil moisture and temperature.

In the area under investigation where low moisture contents and large temperature variations are likely to be experienced, appreciable accumulation of moisture under the floors may occur. The site should therefore be well drained and in some areas sub-soil drainage may be necessary. Attention may be given in the design of floors to allow the accumulated moisture under these floors to evaporate into the room atmosphere which would have the additional desirable effect of increasing the Relative Humidity of room air in hot and dry summer months.

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1. In plate 47 notice that the front wall facing south-east (with open door) of the dwelling on the far right has barely been affected by this heavy rain except at the parapet. Compare it with the completely wetted wall facing north-east of another dwelling on the far left.

2. Relative Humidity of the water vapour is defined as the pressure of water vapour in soil expressed as percentage of the saturated vapour pressure at the same temperature. For a further discussion of moisture movement in vapour phase see: ROAD RESEARCH LABORATORY (UK), "Soil Mechanics for Road Engineers", H.M.S.O., 1952, pp.11 and 329.

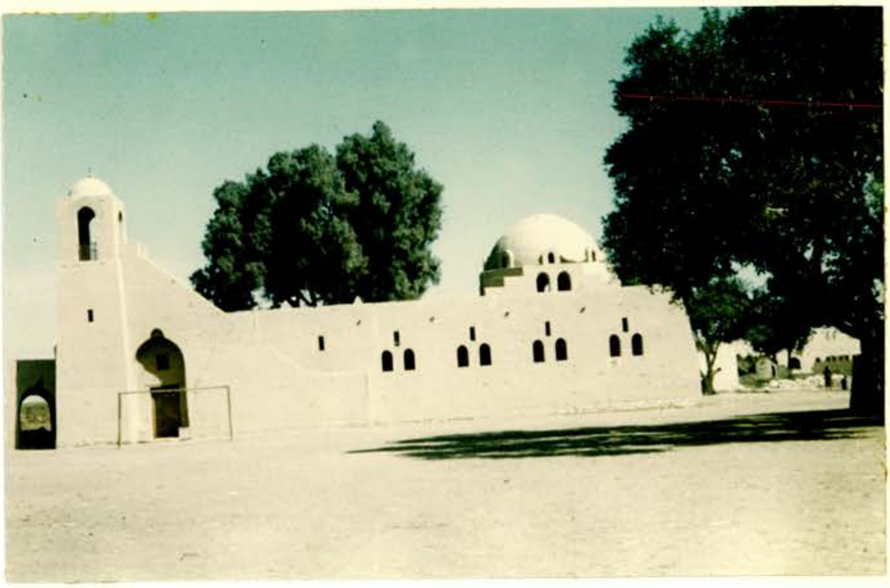

PLATE 7.

The village mosque of Alqurna. An example of successful exploitation of the plastic qualities of earth.

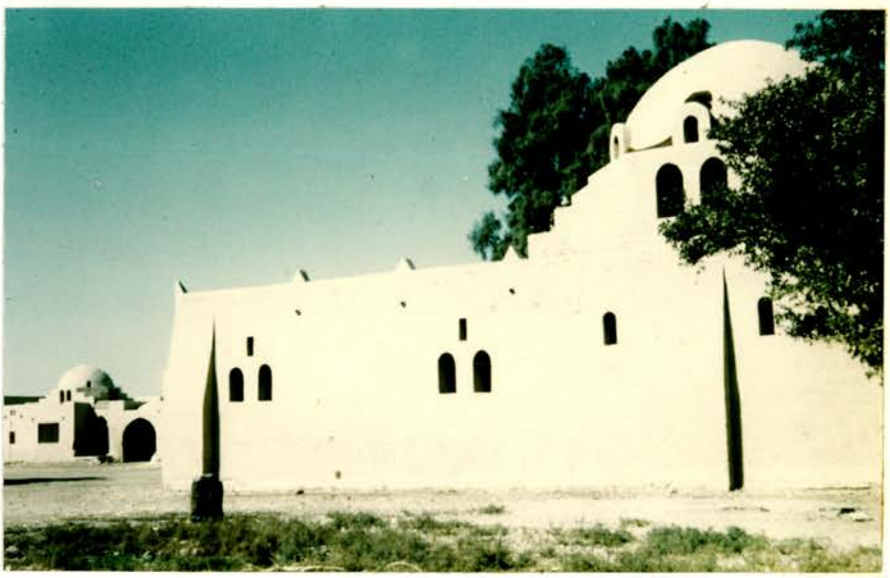

PLATE 8.

A close-up of the mosque wall. Notice the tapering and the buttressing of the high wall as a recognition of low flexural strength obtainable with this material used as such.

PLATE 9.

Structural principles were simple and based on centuries of tradition; well-tried forms like domes and vaults were used as roof structures.

PLATE 10.

Underside of a dome - the holes are to let in the daylight.

PLATE 11.

Some forms were used in rather daring manner and with success. Notice buttressing of the outer walls supporting vaults; and tapering of the edges of the vaults to avoid internal stresses.

PLATE 12.

A close-up of the vaults which are less than 6 inches thick erected with interlaced bonding of adobe brick.

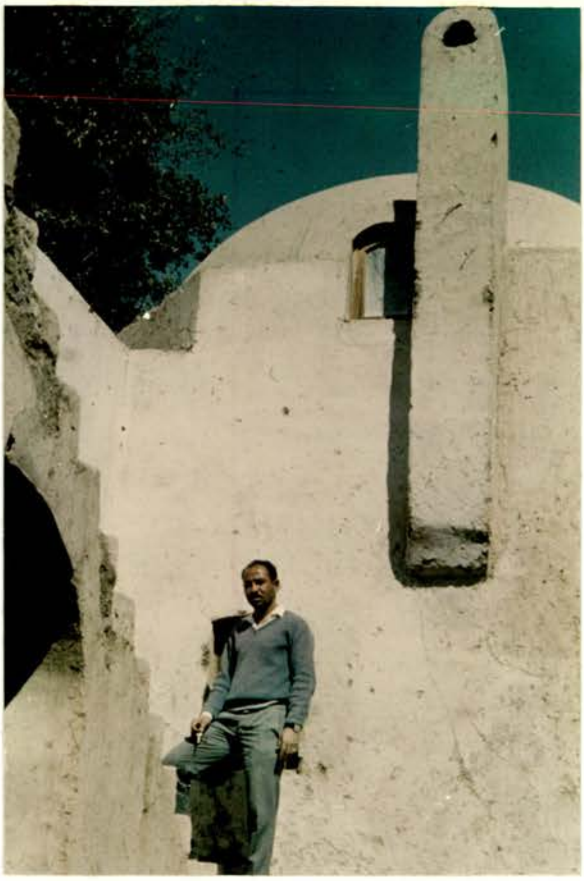

PLATE 13.

General details reflect a sympathy for the qualities of the material. Notice an unpretentious staircase supported on an arch.

PLATE 14.

A part of the village community centre shows that sufficient attention to detail was given as is noticeable in the use of stone as foundation-cum-damp proof course. Notice also the use of stone even at the lower portions of the arch.

PLATE 15.

The beginning of the trouble due to failure to keep up with persistent maintenance demanded. The worn-off plaster allowed rainwater to penetrate, resulting in the disintegration of structures even though they were based on sound principles.

PLATE 16.

The vault of a house severely cracked yet intact. The occupants moved out, salvaging whatever they could.

PLATE 17.

A distant view still gives a glimpse of its original character.

PLATE 18.

Although many of the roof structures are still intact, the walls supporting them reveal serious structural failures.

PLATE 19.

Notice some belated attempts to repair the structures on the far right.

PLATE 20.

Even the dwellings whose roofs are intact are too dangerous to live in, therefore deserted.

PLATE 21.

The remains of the village school which cannot even be cleared now to recover the rich agricultural land it occupies.

PLATE 22.

The dome has fallen only after the supports gave way. Spectacular achievement of a few drops of otherwise welcome rain.

PLATE 23.

Alqurna today - the 'model village' that was to serve as an example, and perhaps it has.

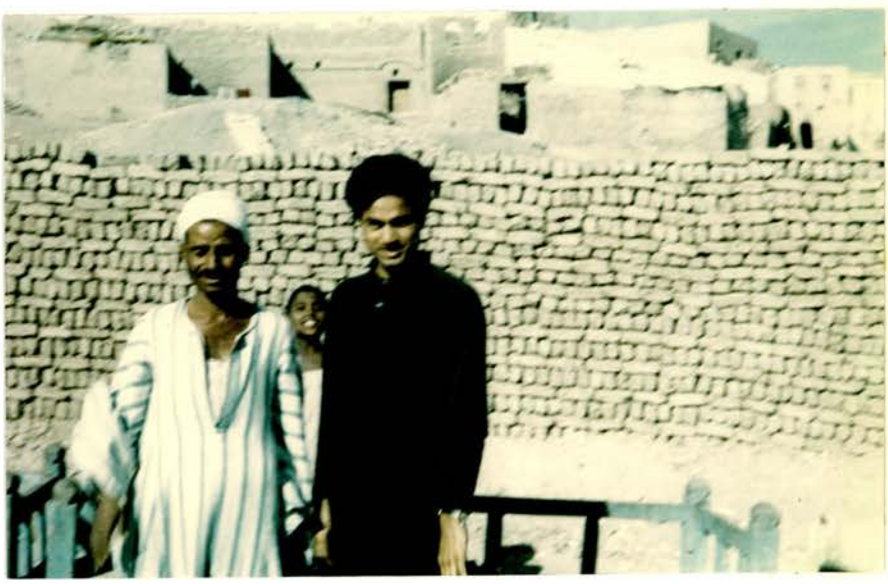

PLATE 24.

End of a sad tale. The sheikh with the old village in the background, "Confine your theories to your books, spare our poor souls".

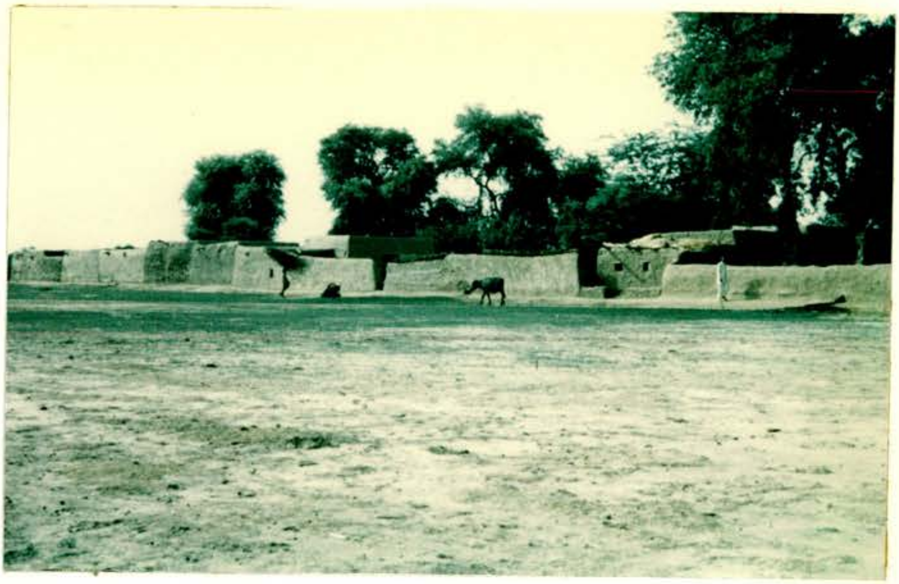

PLATE 25.

Villages in the areas brought under cultivation during the early part of this century are laid out on vast flat sites.

PLATE 26.

The streets are very wide and dusty during the major part of the year, becoming muddy in the rainy season.

PLATE 27.

Cob method of construction in a very crude and make-shift style is employed with no signs of any intuitive appreciation of the form or the potentialities of the material noticeable in many primitive villages.

PLATE 28.

The building process is a co-operative activity; all members of the family help according to their capacity.

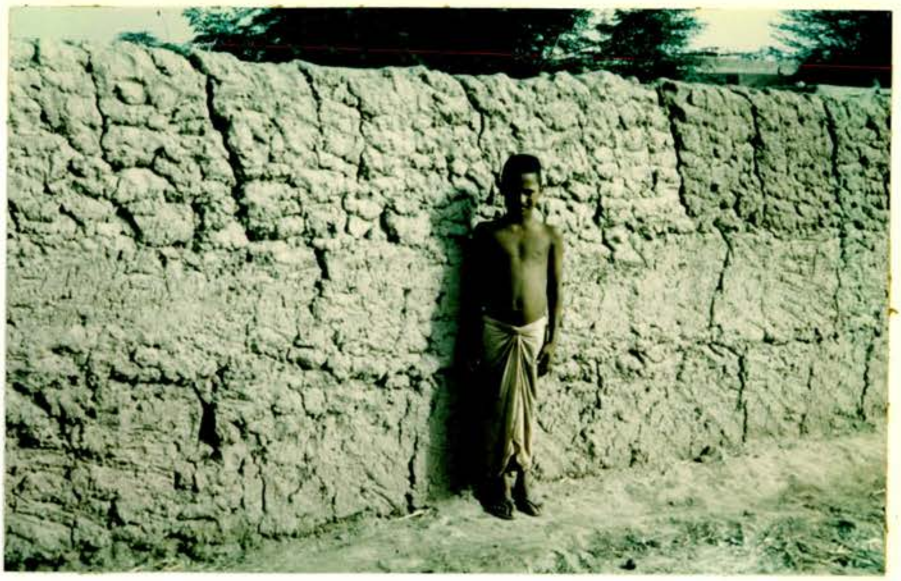

PLATE 29.

The walls are left to dry out for as long as one year till the beginning of the rainy season before they are plastered.

PLATE 30.

The soil is dug from as near the site as practicable.

PLATE 31.

The texture and colour of the soil is generally fairly uniform up to reasonable depths.

PLATE 32.

The ditch from which the soil is dug for building purposes keeps growing in size and accumulates rain water during the wet months.

PLATE 33.

The house drainage also finds its way in the streets and ultimately to these ponds.

PLATE 34.

The rainwater accumulated in these ponds is used in further construction.

PLATE 35.

The plots are enormously large in most cases, originally intended to cater for future expansion of the families. Notice in the aerial view the proportion of the covered area (two rooms in the far corner) to the courtyard.

PLATE 36.

Walling up of these huge courtyards is a necessity for reasons of privacy and security. Notice one-room dwelling with long courtyard wall as seen from the street.

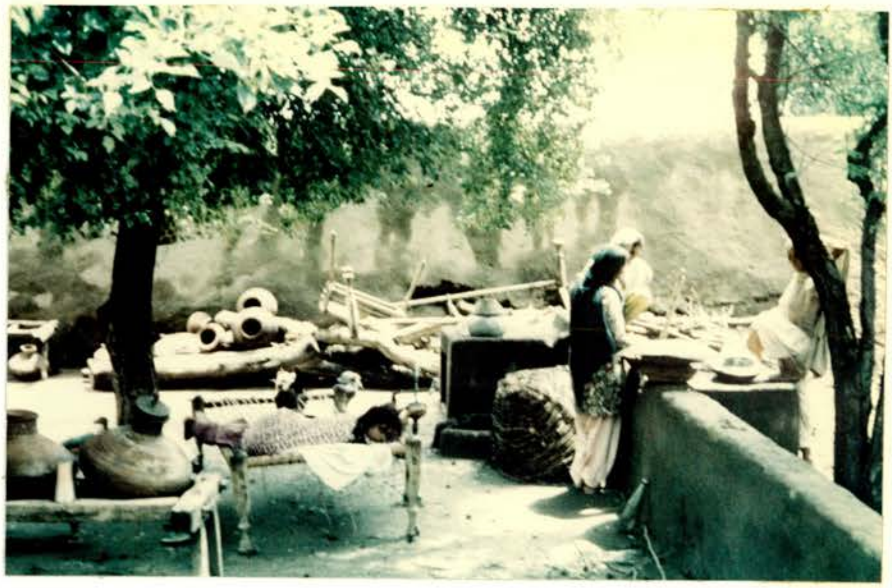

PLATE 37.

Provision of courtyards nevertheless cannot be dispensed with. They form an important living area, most of the activities being performed within this open enclosed space.

PLATE 38.

Courtyards are also necessary to keep the animals in; and under the family's watchful eyes.

PLATE 39.

Annual rainfall is not heavy but it is intensive, occurring in few weeks of the year only, accompanied by fairly strong winds. A street just after such a downpour.

PLATE 40.

There being no drains, the rainwater sometimes remains in the streets for days after a heavy rainfall. Notice the effects of rising damp on the walls.

PLATE 41.

This wall facing south-east has only partially been wetted and that too only from top and bottom because the driving rain was from the north.

PLATE 42.

A peculiar sight after the rainy season. Notice that the plaster that has not yet fallen off is also detached from the wall.

PLATE 43.

The plaster from an entire section of the wall has worn off, so has the occupant's trust in this material.

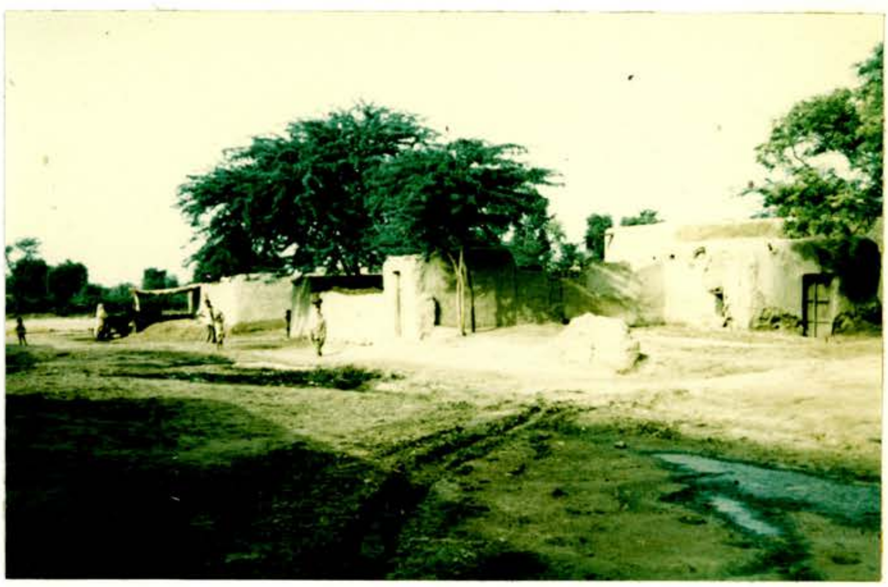

PLATE 44.

This is what most dwellings are eventually reduced to: entire courtyard wall fallen off after years of exposure. The effects of rising damp are beginning to make themselves evident on the walls of the single room dwelling itself.

PLATE 45.

Failure is not confined to outer walls, as notice here a portion of the wall of the house has fallen off.

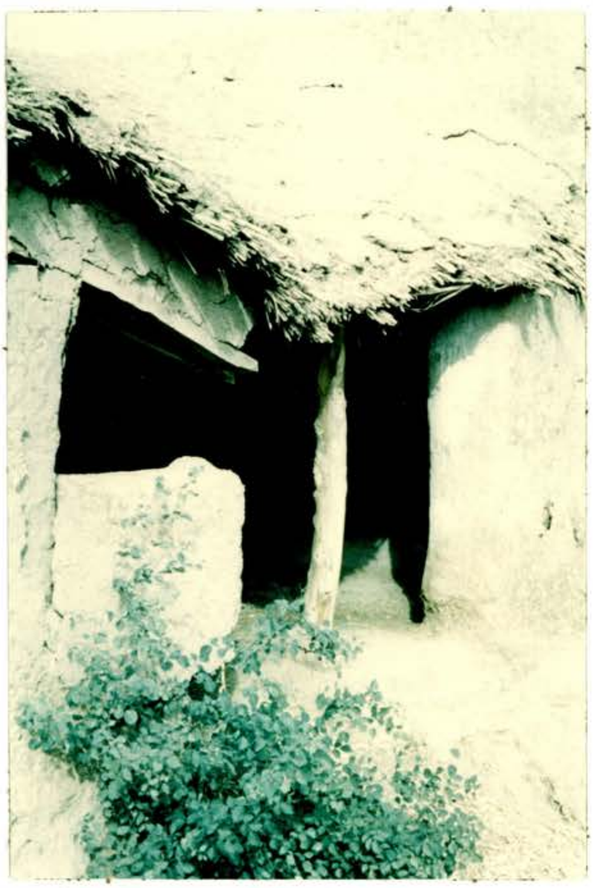

PLATE 46.

The acceptance of defeat, due to failure of this material to stand up to the climatic factors, is reflected in this attempt to support the heavy roof load on a post.

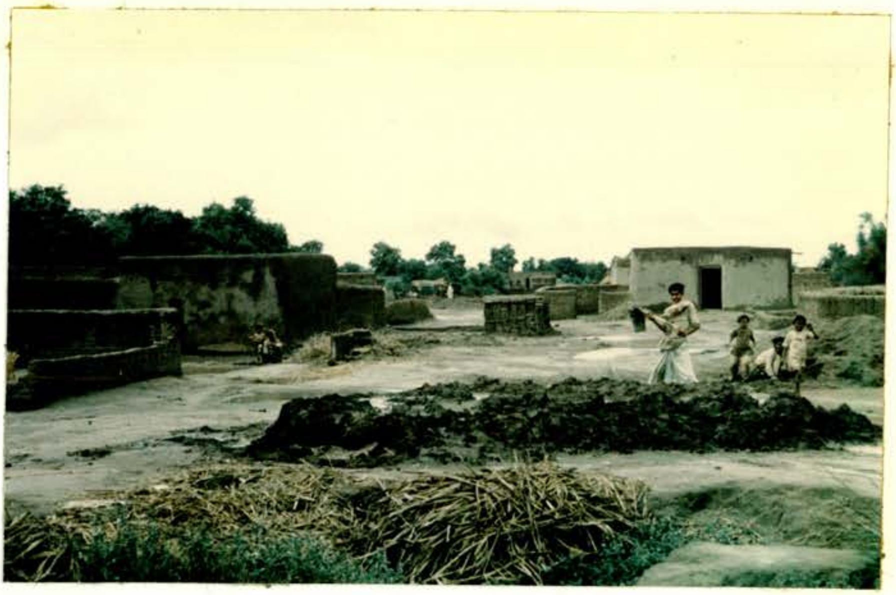

PLATE 47.

Those who still have some determination left have to start the building activity all over again soon after the Monsoons.

PLATE 48.

A continuous nerve-breaking cycle.

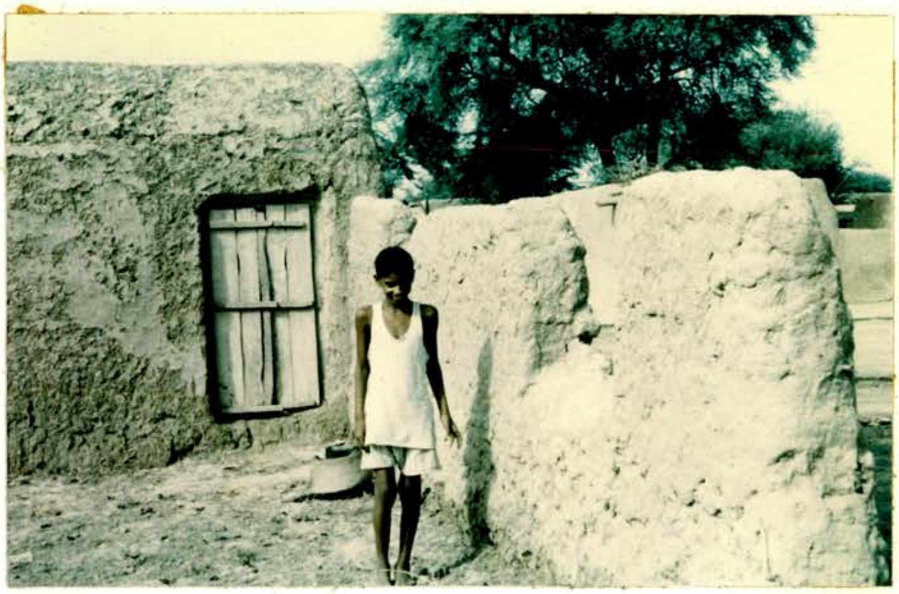

PLATE 49.

The owner of this one-roomed dwelling has resigned himself to fate, having no time to spare from earning his two square meals.

PLATE 50.

This family, 'affluent' by local standards, has invested a fortune in building this single-room of burnt brick, transported over considerable distance, in order to get rid of repeated troubles. Has it really?

CONCLUSIONS TO PART I

(REFER TO PART IV)

A brief review of the housing requirements and the available resources presents a grim picture. The inadequacy of these resources combined with the present pattern of the national expenditure gives little support to the hope that the government would be able to undertake housing programmes commensurate with the requirements. An individual's own resources would therefore have to be relied upon in the main for quite some time to come. The rural and sub-urban population is mostly at subsistence level. This factor weighed against the cost of the primary building materials hardly leaves any room for the possibility of utilizing these materials in any appreciable quantity. Soil was found to be the only available material which the majority of the people can afford due to its ready availability at no cost.

An examination of the past and contemporary examples of earth housing offered some specific lessons, even if only in a negative way. A real intuitive appreciation of the formal properties of this material and a mature imagination was noticed in the most ancient and the most primitive contemporary structures. On the other hand its technical and physical properties have been little understood even in some of the most talked about contemporary projects which due to grave failings of strength, durability and weather resistance have added to the confusion and frustration of the layman as regards the capability of this material in providing a dwelling safe to live.

People living in earth houses today are continually engaged in a struggle against the climatic elements, the severest of which is driving rain. Rapid developments in the engineering properties of the soil for use in airfield and road construction in recent years seem to be quite capable of helping them in this struggle. Soil, when treated with small amounts of Portland cement and compacted at certain moisture contents, has been found to improve remarkably in its resistance to these elements.

Portland cement is about the only commercial entity needed as additive in the stabilization of soil. Thisfortunately is also one of the few building material industries based wholly on indigenous raw material. The presence of large deposits of limestone would make it possible for this industry to expand as the demand for Portland cement increases due to its use in soil stabilization. This expansion should also make it possible for the prices to be lowered. It would be a feasible proposition for the government to subsidize the cost of cement for house building purposes.

An answer to the housing problems in the rural and sub-urban areas of West Pakistan is thus not in importing any new materials and techniques in the area but in revitalization of earth, which already provides shelter to about 86% of the population in these plains.

PART II

LOCATING THE RESOURCES

FOR STABILIZED EARTH HOUSING

CHAPTER 3

THE SOILS IN WEST PAKISTAN

In studying the characteristics of the soils and in predicting their potentialities for use in stabilized earth housing in West Pakistan, we cannot work with the whole continuum at once. Soils have to be grouped into identifiable units and some criteria for such grouping be established. This chapter tries to identify such criteria which would later form the basis of a detailed and comprehensive soil investigation in a selected region.

The soils of West Pakistan plains have been formed by physical, chemical and biological processes taking place on the sedimentary and igneous rocks in the Himalayan mountains and their foothills.[1] The sediments from these mountains were carried down to the sea and deposited there. This sea is believed to have existed in geological times extending from Nainital (in India) to Attock in the north-west of West Pakistan.[2]

These soils, like any other soil, may be regarded as compounds of solid, liquid and gaseous matter. The solid matter is composed of mineral fragments in various stages of disintegration and decomposition. The solid components with the greatest degree of disintegration include sands, silts and clays. Mixed with these is the varying amount of organic matter and mineral salts which are usually found to be concentrated in the upper layer of the soils.

An inquiry into the effects of the major components of soil, i.e. organic matter, moisture and inorganic matter, is followed up with an

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1. West Pakistan plains will be hereafter referred to as the Indus Basin.
2. Private communication with the Geological Survey of Pakistan, Rawalpindi.

investigation in each case to determine the nature and extent of these conditions in the soils of the Indus Basin as a whole.

3.1 ORGANIC MATTER IN THE SOILS

3.1.1 Source of Organic Matter

The source of organic matter in the soils is animal or plant remains which are added to the soils when organisms die and which subsequently undergo decomposition at different rates due to chemical and bacterial action. The fraction of animal origin is relatively small and does not tend to accumulate in the soil, since it is decomposed fairly rapidly and decomposition products utilized as nutrient compounds by living plants. The fraction of vegetable origin on the other hand is relatively large, and persists in the soil for a longer period owing to the comparatively higher resistance of some plant material to decomposition. The total amounts of both kinds of organic matter in the soils were found to be a function of the rate of supply from dead organisms and the rate of decomposition into products which are subsequently removed from the soils.[1]

3.1.2 Effects of Organic Matter

The following spheres of influence of organic matter are important in relation to the use of soil in housing.

3.1.2.1 Hardening. It has been established that organic matter has an important influence in stabilization of the soils with Portland cement.[2]

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1. ROBINSON, G.W., "Soils - their origin, constitution and classification", Thomas Murby and Co., London, 1936.

2. PORTLAND CEMENT ASSOCIATION, "Factors influencing Physical Properties of Soil-Cement Mixtures", Earl J. Felt, 1955, p.138.

From the literature on the subject it has not, however, been possible to determine the concentration of the organic matter at which it begins to affect the characteristics of a soil. It has been observed that its main influence lies in its effect on the hardening of the soil-cement mixtures. Significant effects, probably of a chemical nature, have been observed in connection with cement stabilization when as little as .5 percent by weight of organic matter has been present, but no noticeable influence on the physical characteristics of a soil occurred until the concentration rose above 2-4 percent.[1]

<u>3.1.2.2 Stability</u>. The organic matter also has undesirable characteristics from a purely structural point of view, the chief of which are the open spongy structure and the mechanical weakness of the constituents. It will undergo considerable volume changes when subjected to load or changes in moisture content. The natural moisture content may also be very high, thereby giving a low mechanical stability.

<u>3.1.2.3 Corrosion</u>. The acidic nature of the constituents tends to give an acidic reaction to the water in soil which in turn may have a corrosive effect on the metals in contact with the soil.

3.1.3 Locating the Organic Matter in the Soils

In the Indus Basin organic matter was generally found to be concentrated in the top 12 inches of the soil.[2] Exceptions were noticed in certain areas where leaching in sandy soils was said to be responsible for causing the soluble constituents to be extracted and deposited lower down. The distribution of organic deposits such as those of peat,

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1. <u>ROAD RESEARCH LABORATORY</u> (UK), "The Effect of Soil Organic Matter on the Setting of Soil-Cement Mixtures", H.M.S.O., 1962.
2. <u>UNITED NATIONS SOIL SURVEY PROJECT</u>, Lahore, West Pakistan.

lignite or coal, being conditioned by geological factors, would no doubt extend to much greater depths.

It has been shown that organic matter adversely affects the stabilization of soil with Portland cement. It would therefore be necessary on each site to discard the top 12 inches layer of the soil.[1]

3.2 WATER IN THE SOILS

3.2.1 Source

The soils in the Indus Basin are likely to accumulate moisture from two main sources, from abive due to rainfall and from below due to rise in groundwater table. Moisture from above due to climatic factors presents no significant difficulties from the viewpoint of soil stabilization. The rainfall in any part of the Indus Basin is not heavy enough to cause problems of excessive moisture in the soils. This is generally true even in the Monsoon season because the rainwater is quickly absorbed by the otherwise dry soil; most of it being later evaporated into the atmosphere due to high temperatures and low humidity. The phenomenon of water from below is, however, peculiar to the kind of situation in the Indus Basin. Due to the importance of this factor for earth housing a fairly detailed assessment of the situation was felt to be necessary and is carried out later in this chapter.

3.2.2 Effects

The effect of water on soils can be observed in two distinct ways: its physical influences and effects as a solvent.

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1. Ibid: concentration of organic matter in top 12 inches of soil was found in nearly all cases to be above 2 percent by weight.

3.2.2.1 Physical Influences. These are effects due to liquid characteristics and are manifest in the following phenomena:

a) Cohesion: Mechanical cohesion of the soils is believed to be due mainly to the presence of water. The individual particles in the soil mass are held together by films of moisture.[1] This property of the soils is of fundamental importance in stabilization because their cohesion can be changed and improved by appropriate methods.

b) Swelling: This effect is associated with hydration of particles in clay soils. During the wetting of a clay the thickness of existing moisture films grows thereby increasing the effective solid volume associated with each particle.[2] If the layers of moisture films are in contact with each other, the total volume of the soil structure will also increase due to this increase in the thickness of the individual layers. This is the principal cause of the disintegration of the earth structures exposed to this effect due to rains.

c) Shrinkage: It is usually associated with loss of moisture due to evaporation. The reverse of the phenomenon described in swelling occurs reducing the volume of the total soil.

d) Plasticity: When a mass of soil is subjected to stress above its elastic limit, it will be deformed and ruptured. If the soil is cohesive, however, and its moisture content is high enough, deformation is not accompanied by a breakup of the structure but plastic flow takes place instead. Plasticity is a characteristic of all cohesive soils, and relationship between the plastic properties of a soil and its constitution and mechanical performance are of considerable importance in soil stabilization.

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1. SOIL SCIENCE, "The condition of water in porous systems", by Winterkorn, H.F., 1956, p.110.
2. Ibid.

e) Compaction: This effect is also dependant upon lubrication of the soil particles by moisture, in which the particles are made to pack more closely together through a reduction in the air voids, generally by mechanical means.[1]

f) Permeability: Hydrostatic forces may be developed due to some externally applied pressure giving rise to movement of moisture in soil. The rate at which this movement occurs is affected partly by the magnitude of these forces and partly by the resistance offered by the soil.

3.2.2.2 Effects as a Solvent. In addition to its purely physical properties the water in soil possesses characteristics of interest due to its action as a solvent. The soluble salts are dissociated in solution giving rise to positively charged ions (cations) of such metals as Sodium, Calcium, Magnesium and Aluminium which have the property of being adsorbed on the surfaces of the soil particles. Such ions are often referred to as exchangeable bases, and the nature of exchangeable bases in a soil can influence its physical properties to a considerable extent.[2]

A rise in groundwater table can also lead to crystallization of some soluble salts. When a considerable upward movement of moisture occurs, it may transport with it dissolved salts such as Sodium Sulphate and concentrate the salts in the surface strata of the soil, where they crystallize and disrupt the soil structure. This phenomena is called 'Salinity' and will be looked into later.

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1. This aspect will be considered in detail in Chapter 9.
2. For a fuller discussion of 'Base Exchange' see: METCALF, J.B., "Soil Stabilization and its Application to Road Pavements", Ph.D. (Civil Engg.) Thesis, Leeds, 1958, p.12.

Another serious effect of the groundwater table reaching too near the surface occurs in the form of what is known as 'waterlogging'. A waterlogged soil is that where the subsoil water table has risen to such a height that the evapotranspiration starts due to capillary action. Any further rise of water table diminishes because the additional rise is counterbalanced by the evapotranspiration.[1] This type of situation is likely to be very detrimental to stabilization process due to excessive moisture present in the soils.

3.2.3 Locating the Ground Water Table

The problem of waterlogging being fairly extensive in the Indus Basin, it was necessary to try to isolate regions which may give unsatisfactory results if stabilization were carried on there. There being little abrupt variations in the groundwater table it was possible to prepare a general reference map showing ground water contours. (See Reference Map 4 in Part IV.)

<u>3.2.3.1 Ground water under pre-irrigation conditions</u>. The canal irrigation of the arid and semi-arid zones of the Indus Basin was started 70-80 years ago. Before the introduction of canal irrigation, the water table in the upper part of the Indus Basin in the Punjab area at the deepest positions was 90-100 feet near Lyallpur, 40 feet near Sialkot and Sheikhupura, 30 feet near Pasrur. In the rest of the Rachena Doab it ranged between 20-40 feet.[2] In the southern part of the Indus Basin in Sind area, the water table was also beyond 20 feet. The areas

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1. Private communication with Director, Soil Reclamation Directorate, Lahore, West Pakistan.
2. 'Doab' is the local name for the area lying between two confluent rivers. The names for different 'doabs' are derived by combining a few letters of each of the two rivers, e.g. '<u>Rachena</u> Doab' lies between the rivers <u>Ra</u>vi and <u>Chena</u>b.

forming the active flood plains adjacent to the rivers, however, had a water table within 10 feet in both upper and lower parts of the Indus Basin. At that time the groundwater hydraulic system was in a state of dynamic equilibrium. There was no long-term rise or fall of water table and the recharge from the infiltration of rivers and rainwater to the groundwater reservoir balanced the discharge under the natural evapotranspiration process (see Fig.3).[1]

<u>3.2.3.2 Ground water under irrigated conditions</u>. The equilibrium was upset by leakages mainly from the new canals (nearly 41,000 canal miles) and water courses emerging from 60,000 outlets.[2] Losses from the distributaries range from less than one cusec per mile for the small distributaries to over 20 cusec per mile for the main canals. At least 33 percent of annual head supplies percolate downward to the natural water table.[3]

In the lower part of the Indus Basin, namely Sukkur and Gudu right bank, the infiltration of applied irrigation is the major source of recharge. The Sind practice of 'pancho' with continuous flow of water over rice fields to provide temporary relief from reducing conditions is an instance of wastefully heavy irrigation. The rate of rise of the water table has been recorded to be in the order of 1 to 1.7 feet per year until it came within 30 feet of the surface. As the water table became higher the rate of rise correspondingly became slower as shown in the following Table.

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1. Data supplied by Directorate of Land Reclamation, Lahore, West Pakistan.
2. One canal mile = 5000 feet.
3. Annual head supplies amount to 70 million acre feet.

TABLE 20 GROUND WATER UNDER IRRIGATED CONDITIONS

Water Table (Depth from soil surface in feet)	Rate of Rise (per year in feet)
30 and above	1.0 - 1.7
15-30	0.3 - 0.7
5-10	0.1

It is noticed that at some depth between 5-10 feet from the natural surface the rising water table attains a stable position showing only seasonal fluctuations, and thus a new equilibrium is established depending upon the land elevation, intensity of irrigation, seepage from canals and climatic factors.

The latest overall situation as regards soils affected by the ground water is shown in Table 21 and summarised below.

a) The Doabs. Rachena, Chaj and Bari doabs having extensive irrigation systems are considerably affected by waterlogging. About 73, 50 and 21 percent of Chaj, Rachena and Bari doab respectively fall within the water depth zone of 0-10 feet from ground surface. In Bari doab more severely affected areas are in the southern part of Multan and in the northern parts of Montgomery and Lahore districts. A further breakdown of the water table depths in the areas likely to have undesirable effects is given in Table 22. Drainage schemes in these areas, completed and under construction, are likely to improve the situation considerably.

b) Bahawalpur. Water table in most of the cultivated areas in Bahawalpur is within 15 feet of the surface and in most parts the underground water is highly saline. At present severe waterlogging exists in the area irrigated by Eastern Sadiquia canal north-east of the town of Bahawalpur, and along the upper part of Panjnad canal in Rahim yar Khan. The Bahawalnagar area suffers from a shortage of irrigation water as well as of waterlogging.

c) Sind. The water table in about half a million acres of Larkana and Shikarpur fluctuates between 7-9 feet during rice cultivation and dry seasons respectively. There are large areas with high water table in which the water constantly continues to rise to the surface and deposits salts after the water has evaporated. One such area is the broad plain of upper Indus, stretching 200 miles along the right bank of Indus from Dadu 75 miles above Hyderabad to Kandhkot and Kashmore. The other region of waterlogging is the lower Sind plain and the Indus delta which are irrigated by the canal system of new Gulam Mohammed Barrage.

3.3 INORGANIC MATTER IN THE SOILS

3.3.1 Source

The source of the inorganic or mineral components, which form the main bulk of a soil, lies in the various types of rocks occurring in the earth's crust. These components are formed due to soil forming or 'pedogenic' processes which may be both of physical and chemical nature.[1]

The mineral matter in soil usually occurs in the form of solid particles of different types. An investigation of soils based on particle sizes will be taken up in Chapter 4; this section deals with the problem of inorganic salts in the soils. These salts may be present either in solution or in crystallized form. In addition to the inherent salts in the soil profile, the irrigation water is also the source of salts.

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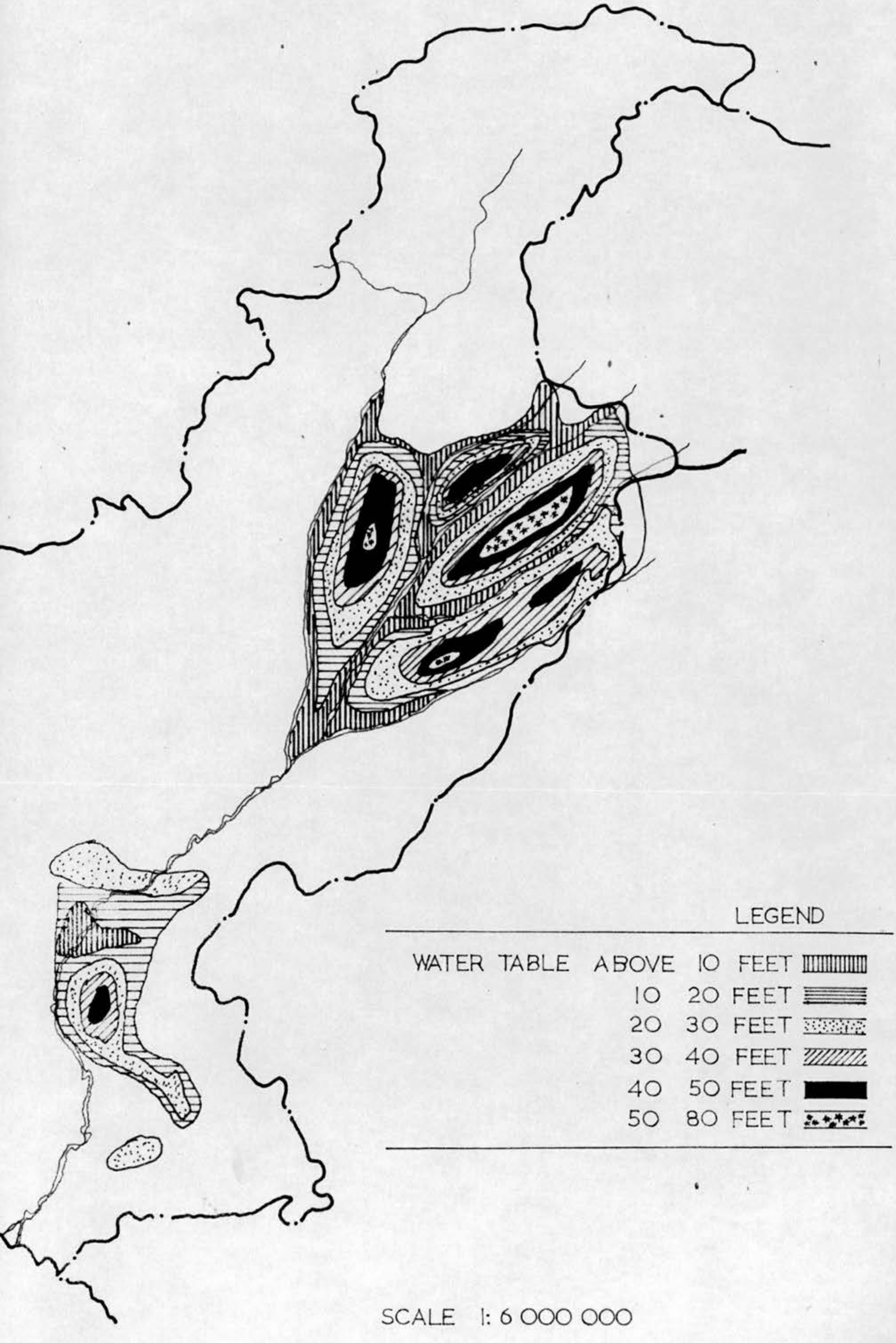
1. JENNY, H., "Factors of Soil Formation", McGraw Hill Book Co. Inc., New York, 1941.

G: 3 EARLIEST WATER TABLE CONDITIONS



SCALE 1: 6 000 000

TABLE 21

WATER-TABLE DEPTH ZONES IN VARIOUS REGIONS OF WEST PAKISTAN (JUNE 1959)

Name of Region	Total area in acres	Area falling in							
		0-5 ft. (acres)	%age	5-10 ft. (acres)	%age	10-15 ft. (acres)	%age	Beyond 15 ft. (acres)	%age
1.Peshawar area	17623040	20787	.11	182067	1.03	106496	0.60	17313690	98.24
2.Chaj Doab	3229000	432200	13.39	1926400	59.66	442000	13.68	428400	13.26
3.Rachena Doab	6916000	483400	6.98	2982800	43.12	1886400	27.27	1563400	22.60
4.Thal and Derajat	12786173	250000	1.95	1650000	12.90	950000	7.43	9936173	77.71
5.Bari Doab	65536000	16783	0.25	1365903	20.81	1780838	27.17	3390076	51.72
6.Bahawalpur area	10667187	240000	2.25	990000	9.28	1210000	11.34	8227187	77.11
7,Sind area	35926080	572621	1.59	3346152	9.31	1286349	3.58	30720958	85.51
TOTAL	93701080	2015791	2.15	12443322	13.28	7662083	8.18	71579884	76.39

TABLE 22

WATER TABLE DEPTHS ZONES

(Breakdown of Regions)

S. No.	Name of area	Total area (acres)	Water Table (feet below land surface)				
			at surface	0-3	3-5	5-10	more than 10 ft.
	RECHNA DOAB						
1.	Chickoki Mallian Shadman	160,000	-	17,000	82,000	56,800	4,100
2.	Shah Kot	247,200	1,600	15,100	67,400	86,000	77,100
3.	Chuharkana	10,800	100	6,700	3,200	700	100
4.	Pindi Bhattian	8,300	-	200	400	700	7,000
5.	Khangah Dogran	121,800	1,800	11,900	66,800	30,400	10,900
6.	Jaranwala	90,000	-	600	8,700	36,300	45,300
7.	Hafizabad Thatta	131,300	600	19,600	74,400	32,400	4,300
8.	Hare Sheikh	115,400	1,700	13,300	31,900	23,500	45,000
9.	Sangla Hill	150,700	1,600	23,600	72,600	49,900	3,000
10.	Beranwala	125,900	700	23,100	38,600	35,900	27,600
11.	Zafarwal	204,200	1,600	2,400	19,900	48,700	131,600
	CHAJ DOAB						
12.	Lalian	198,000	3,700	5,000	29,600	56,300	103,000
13.	Maggowal	45,400	-	2,200	16,600	21,600	5,000
	THAL DOAB						
14.	Muzaffargarh	89,500	5,100	13,400	65,200	5,700	100
15.	Lower Thal excluding Muzaffargarh	1190,500	15,000	15,600	356,800	538,300	20,500
	TOTALS	2,889,900	33,500	211,200	934,100	1023,200	484,600

3.3.2 Effects

The amount and the nature of the salts present in the soil affect the alkalinity or the acidity of the soil which in turn has a marked effect on the physical properties of the soil.[1]

In addition to this the soluble salts themselves may affect in various ways the soil or structure in contact with it by:

a) Attacking concrete and other materials containing cement.

b) Disrupting porous materials such as the soil itself by crystallization.

c) Corroding metals, such as iron pipes.

The following table shows the criteria used to define the degree of salinity of a soil.[2]

TABLE 23 EFFECT OF SALTS ON SOIL

Mapping[3] symbol	Salt content	P^H value[4]	Soil Characteristics
No symbol	Lower than 0.2	Less than 8.5	Normal soil
S_2	Lower than 0.37	8.5 - 9.0	Slightly saline
S_3	0.37 - 0.5	Below 9.0	Moderately saline
S_4	Above 0.5	Above 9.5	Strongly saline

1. Alkalinity or acidity of a soil is quantitatively measured through determination of its P^H (Hydrogen ion concentration). See Chapter 5.
2. This classification of saline soil is based on the laboratory and field experiments conducted by the Soil Reclamation Directorate on West Pakistan soils between 1927-1940.
3. These symbols are used in Reference Map 8 in Part IV.
4. P^H is the measure of Hydrogen ion concentration.

3.3.3 Locating Salinity in the Soils

The salts from sea water and those resulting from the mineral decomposition were more or less uniformly distributed throughout the soil profile under pre-irrigation conditions. With the introduction of irrigation and subsequent rise in ground water table the salts concentrated at the surface depending upon the load of irrigation. The soil profile of the Indus Basin is characterized generally by the presence of sodium salts predominantly of sulphates, chlorides and carbonates. In the northern part of the Indus Basin (Panjab and Bahawalpur areas) the predominating salt is sodium sulphate whereas the lower part of the Basin (Sind) is impregnated with sodium chloride. Apparently sodium carbonate is not found in Sind soils.[1] As already mentioned these soils may be the remnant of the period when alluvium was deposited in the sea water.

With the rise of water table under the influence of capillarity in the majority of the areas of varying salt concentration of ground water, salts are being added at the rate of 1450 lbs to 8000 lbs per acre per year, in the northern region of Punjab. In Chaj, Rachena, Bari and Thal, constituting an area of 16.4 million acres, about 4.36 million acres have saline ground water containing over 1000 parts per million. In the lower Thal area the saline water is confined to a limited area of 0.30 million acres out of a total of 1.4 million acres. Ground water all over Sind area is saline except those areas which constitute the flood plains or where rice cultivation was practised or in the vicinity of big canals, where the irrigation water had the effect of depressing ground water downwards. In the high delta areas of Gulam

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1. The presence of sodium carbonate is discernible visually since it forms a black layer (locally called 'Kallar') on the soil surface.

Mohammed Barrage and tail of Sukkur Barrage the ground water is very saline within shallow depths. Table 24 shows the overall picture of salinity in West Pakistan; Tables 25, 26 and 27 are figures for each doab; and Table 28 is a further breakdown of these doabs into district wise figures.

This information is later used in the preparation of Reference Maps as described in Part IV.

TABLE 24 SALINITY IN WEST PAKISTAN

Site	Predominantly severely saline (acres)	Area with saline patches (acres)	Poorly drained or water-logged (acres)
PUNJAB			
(a) Sind Sagar Doab	1,80,000	4,50,000	5,10,000
(b) Chaj Doab	1,70,000	5,70,000	6,50,000
(c) Rachena Doab	11,40,000	23,00,000	27,10,000
(d) Bari Doab	1,00,000	5,90,000	40,000
(e) Bhawal Plain	-	1,60,000	5,00,000
Sub Total	15,90,000	40,70,000	44,10,000
SIND			
(a) Indus Corridor	1,00,000	18,80,000	50,000
(b) Upper Sind	10,90,000	21,60,000	32,00,000
(c) Central Sind	2,20,000	19,10,000	10,30,000
(d) Lower Sind	9,90,000	8,60,000	18,50,000
(e) Indus Delta	8,30,000	2,70,000	6,80,000
Sub Total	32,30,000	70,80,000	68,10,000
GRAND TOTAL	48,20,000	1,11,50,000	1,12,20,000

TABLE 25

SALINITY IN RACHENA DOAB

Unit No.	Area in thousand acres	Percentage of the area				
		Non-saline	Slightly saline	Moderately saline	Strongly saline	Unclassified
1.	1,317.8	65	12	8	15	-
2.	2,334.4	79	9	6	4	2
3.	1,944.9	52	28	9	9	2
4.	202.0	82	9	0.5	1	7.5*
5.	265.6	60	12	14	11	3.2
Percentage		66	16	8	8	2

* High percentage of unclassified area is due to large area under forest, channels and nullahs etc.

TABLE 26

SALINITY IN CHAJ DOAB

Unit No.	Area in thousand acres	Percentage of the area				
		Non-saline	Slightly saline	Moderately saline	Strongly saline	Unclassified
1.	1,238.9	60	22	6	10	2
2.	735.5	63	25	8	2	2
3.	819.9	69	22	4	2	3
4.	273.2	86.3	6	0.2	-	7.5*
	Percentage	66	21	5	5	3

* High percentage of unclassified area is due to large area under Nullahs etc.

TABLE 27

SALINITY IN THAL DOAB

Unit No.	Area in thousand acres	Percentage of the area					
		Non-saline	Slightly saline	Moderately saline	Strongly saline	Dunes (unclassified)*	Unclassified
Part of							
5.	39.6	75	6	4	-	15	-
6.	1,000.0	42	14	5	6	32	1
7.	966.0	53	26	7	10	2	2
Percentage		48	20	6	8	17	1

* Because sizeable areas in Lower Thal are under dunes, their percentage is also reported in this table.

TABLE 28 SALINITY IN DISTRICTS

S. No.	Name of District	Total area (acres)	Classification of salinity						Total salinity
			Strongly saline	Moderately saline	Slightly saline	Non-saline	Unclassified	Under reclamation	
1	2	3	4	5	6	7	8	9	10
1.	Gujrat	5,49,565	5,886	1,728	3,243	35,040	229	697	46,823
2.	Sargodha	16,23,966	40,000	17,246	16,984	1,89,564	290	1,973	2,66,057
3.	Lyallpur	20,58,769	35,278	43,880	28,646	2,07,233	2,468	13,229	3,30,734
4.	Gujranwala	10,84,005	60,700	1,18,800	17,394	1,10,993	336	5,530	3,17,753
5.	Sheikhupura	12,56,858	87,159	1,27,957	35,897	2,09,784	115	12,139	4,73,051
6.	Jhang	9,16,329	45,800	3,572	3,912	1,47,999	178	9,890	2,11,351
7.	Multan	32,60,420	1,45,392	12,396	17,550	3,49,076	144	9,844	5,34,402
8.	Montgomery	19,09,505	47,452	25,680	18,249	1,72,139	93	12,229	2,75,842
9.	Lahore	10,00,204	27,050	25,162	8,634	7,33,04	392	38	1,34,580
10.	Sialkot	13,173	203	-	-	290	-	-	493
11.	Muzaffargarh	15,41,372	1,42,620	11,191	17,032	1,26,435	-	30	2,97,308
12.	Mianwali	9,04,876	1,104	802	61	30	-	-	1,997
13.	Dera Ghasi Khan	6,99,319	36,815	4,170	3,704	57,493	290	-	1,02,472
14.	Malakand	25,988	31	-	-	102	-	-	133
15.	Peshawar	2,21,436	4,674	528	80	3,718	-	-	9,000
16.	Mardan	4,09,901	10,833	606	1,260	3,846	7	-	16,552
17.	Bannu	1,38,540	42	640	6,303	1,569	4	-	8,558
18.	Hazara	11,857	-	-	-	-	-	-	-

1	2	3	4	5	6	7	8	9	10
19.	Dera Ismail Khan	1,52,976	1,613	2,847	44	52,515	-	-	57,019
20.	Bahawalnagar	15,34,425	21,557	23,810	11,404	48,642	139	-	1,05,552
21.	Bahawalpur	10,57,635	18,822	4,422	1,814	34,987	56	-	60,101
22.	Rahimyarkhan	15,93,912	89,307	13,628	24,627	1,16,509	-	-	2,44,071
23.	Hyderabad	20,72,777	72,011	34,638	10,368	1,01,140	-	-	2,18,157
24.	Tharparkar	13,80,812	13,155	74,943	11,174	1,78,437	-	-	2,77,709
25.	Sanghar	14,34,219	28,352	68,027	17,140	1,10,812	-	-	2,24,331
26.	Nawabshah	10,40,367	1,306	634	506	29,872	-	-	32,318
27.	Thatta	11,27,126	1,61,767	17,764	17,162	42,917	-	-	2,49,610
28.	Sukkur	21,24,652	1,59,744	17,933	8,366	23,909	-	-	2,09,952
29.	Khairpur	5,78,675	5,735	11,246	6,021	24,706	-	-	47,708
30.	Larkana	11,40,824	1,95,192	64,447	25,392	64,033	-	-	3,49,064
31.	Jacababad	15,77,767	1,88,292	29,256	19,212	64,440	-	-	3,01,200
32.	Dadu	6,87,156	42,026	11,085	5,808	44,385	-	-	1,03,304
33.	Kalat	1,94,399	-	-	-	-	-	-	-
34.	Zhob	2,31,214	67	3,035	2,463	4,289	-	-	9,854
35.	Quetta	10,05,731	44,780	778	5,713	21,240	-	-	72,511
36.	Lorala	6,86,502	24,067	141	13	2,188	-	-	26,409
37.	Sibbi	4,44,319	416	-	-	162	-	-	578
	GRAND TOTAL	3,76,91,573	17,59,249	7,72,992	3,56,176	26,53,798	4,741	69,599	56,16,554

CHAPTER 4

THE SOILS IN THAL REGION

The object of this chapter is to describe briefly how an understanding of the soils and prediction of their behaviour for stabilization purposes was obtained from the results of an agricultural soil survey carried out by an international organization.[1] To achieve this objective an extensive programme of observation, experimentation and correlation was undertaken with full cooperation of this organization. The role of the author in this soil survey was primarily that of an observer; participating in the survey for the purpose of obtaining soil samples but concerned mainly with the results of the analysis of these samples. A system of classification, considered suitable from soil stabilization viewpoint, was adopted and detailed soil maps based on this system were then prepared for a selected region.[2] Assuming the adequacy of the system of classification adopted, it should be possible to make reliable predictions from these soil maps. This, it is hoped, will make possible an orderly application of our knowledge in the field of soil science to our specific area of interest - Earth Housing.

4.1 THE SOIL SURVEY

No detailed description of the soil survey procedures is necessary here because, as stated earlier, this study has relied almost exclusively on the results of the survey conducted by another organization.[3]

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1. UNITED NATIONS SOIL SURVEY PROJECT, Lahore, West Pakistan.
2. See REFERENCE MAP : 8 in Part IV.
3. For further details of soil survey procedures see UNITED STATES DEPARTMENT OF AGRICULTURE, Handbook No.18.

Such an extensive use is later made of these results that a brief outline of the major activities involved in gathering this information however appears to be quite in place.

4.1.1 Preparation for Field Work

Soil survey is a complex operation; many technical details and services of several kinds of specialists and a large number of their staff are involved. Each survey party before setting out for the survey had a clear understanding of the work to be done. General specifications and assignments of each professional worker and participant were set forth in 'Soil Survey Work Plan', whose essential items were:

a) Name, location, size and boundaries of survey area.

b) Description of the principal physical features of the area.

c) List of any previous surveys of soil, relief, geology or vegetation.[1]

d) A list of equipment and transport needed.

e) Names of the workers.

f) Scale of the maps.

A 'Base Map' on 1:6000 (1"=500') was prepared as accurately as possible for each of the areas to be surveyed. As many of the physical features as possible were incorporated into the map. These features included canals, smaller water distributaries, roads, railway track, any structures, trees etc. These physical features and their proper location on the map is of considerable significance since these act as reference points. For the purpose of taking soil samples in an organized manner, a grid at one inch interval (500') was laid on the base map. Each point on the grid was thus defined in reference to some physical features on the map.

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1. Considerable information about the geological and soil conditions was often available from the Survey of Pakistan and land records of respective District Boards.

4.1.2 Site Reconnaissance

A preliminary reconnaissance by visiting the site intended to be surveyed usually provided useful broad indication of the nature of the soil. The general topography often gave some indication as to whether the soil conditions were likely to be variable or not. Some idea about the depth of water table below the surface could often be obtained from an inspection of the village well or, in case of high water table areas, even some ditches. Similarly saline land would sometimes make itself discernible through a white or black layer of salt on the soil surface. A change in vegetation over quite a small area often indicated important changes in the sub-soil or rock formation. A wild plant locally known as 'Dab' was a familiar sight on waterlogged and marshy lands. After the site reconnaissance the preliminary plan of boring had often to be adjusted to site conditions. The revised plan of sample areas depended entirely on the nature of the soil encountered. The distance between bore holes was as much as 1500 feet in very uniform ground or sometimes as little as 100 feet in quickly changing ground.

4.1.3 Obtaining the Samples

After the layout of the borings was finalized, the position of the holes would be pegged on the ground. Except on marshy ground or in very large fields, it was usually sufficiently accurate to set out the positions of the holes by ranging rods or flag poles on the line of the borings. Use of theodolite was rarely resorted to. Post-hole auger of 5 inch diameter was generally employed for obtaining samples.[1] At least one sample was taken from each stratum found in each boring. Samples were placed in separate sample tins and their nature noted on the boring

1. Power augers were frequently used for deeper borings.

record. Full and systematic records were kept of each boring on boring record sheets. Part of the boring records was filled on the field and part subsequently. The description of the site gave the nature of the ground and stated the depth of loose leaves etc. removed before boring. The description of the soil included its colour, texture, consistency, structure and any other characteristics possible to note from visual inspection e.g. organic matter salinity etc. A tentative designation of each soil according to the classification system used was also made at this stage.[1]

The soil samples thus obtained were investigated according to the procedure outlined in the next chapter.

4.2 THE SOIL CLASSIFICATION

Many hundreds of unique kinds of soil exist in West Pakistan; as many as there are genetic factors. The characteristics of each could be learned through observation and research in the field and in the laboratory. The history of the soil and its potentialities are contained in these characteristics, considered collectively. The influence on soil behaviour of any one characteristic or of a variation in any one depends upon the others in combination. Nevertheless, just as no two white pine trees are entirely identical yet all trees called white pine have certain differentiating characteristics in common, so have the soils. In order to organize our knowledge and remember it, recognize individual kinds of soil, see relationship among soils and formulate principles of prediction value, the soils were grouped in accordance with a system of classification developed by the United States Department

1. The system of classification used is described in the next Section.

of Agriculture.[1] A number of other systems were also available. Each has its own merits and shortcomings.[2] None of the present systems in fact was found to provide the answer to all the questions arising in connection with soil behaviour for the purpose of stabilization.

A triangular diagram used in this system of classification to relate the percentages of sand, silt and clay fractions in the soils is illustrated in Fig.4. Shown on the figure are also the recommended limits of particle sizes for defining various soil fractions. Simple field and laboratory tests, as discussed in the next chapter, are used as the basis of classification.

Textural classification illustrated in Fig.4 is described in tabular form in Table 29. It will be noticed from these that thirteen different groupings of basic soil texture have been obtained with various combinations of the three basic soil fractions sand, silt and clay. Each of these textural classes has been assigned a definite range within which their constituent fractions may vary. For example, a soil to be classified as 'sand' must have clay between 0-10 percent, silt between 0-15 percent and sand between 85-100 percent of the total.

These thirteen basic soil types have further been grouped into five main textural soil groups. All the soils encountered in the area covered by the soil survey were divided into these five major groups. Each soil group, however, was assigned a place name instead of its textural name for the sake of simplicity. For example 'Moderately

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1. UNITED STATES DEPARTMENT OF AGRICULTURE, "Soil Survey Manual", Department of Agriculture Handbook No.18.

2. HICKS, L.D., "Use of Agricultural Soil Maps in Making Surveys", North Carolina State Highway and Public Works Commission, USA, p.110.

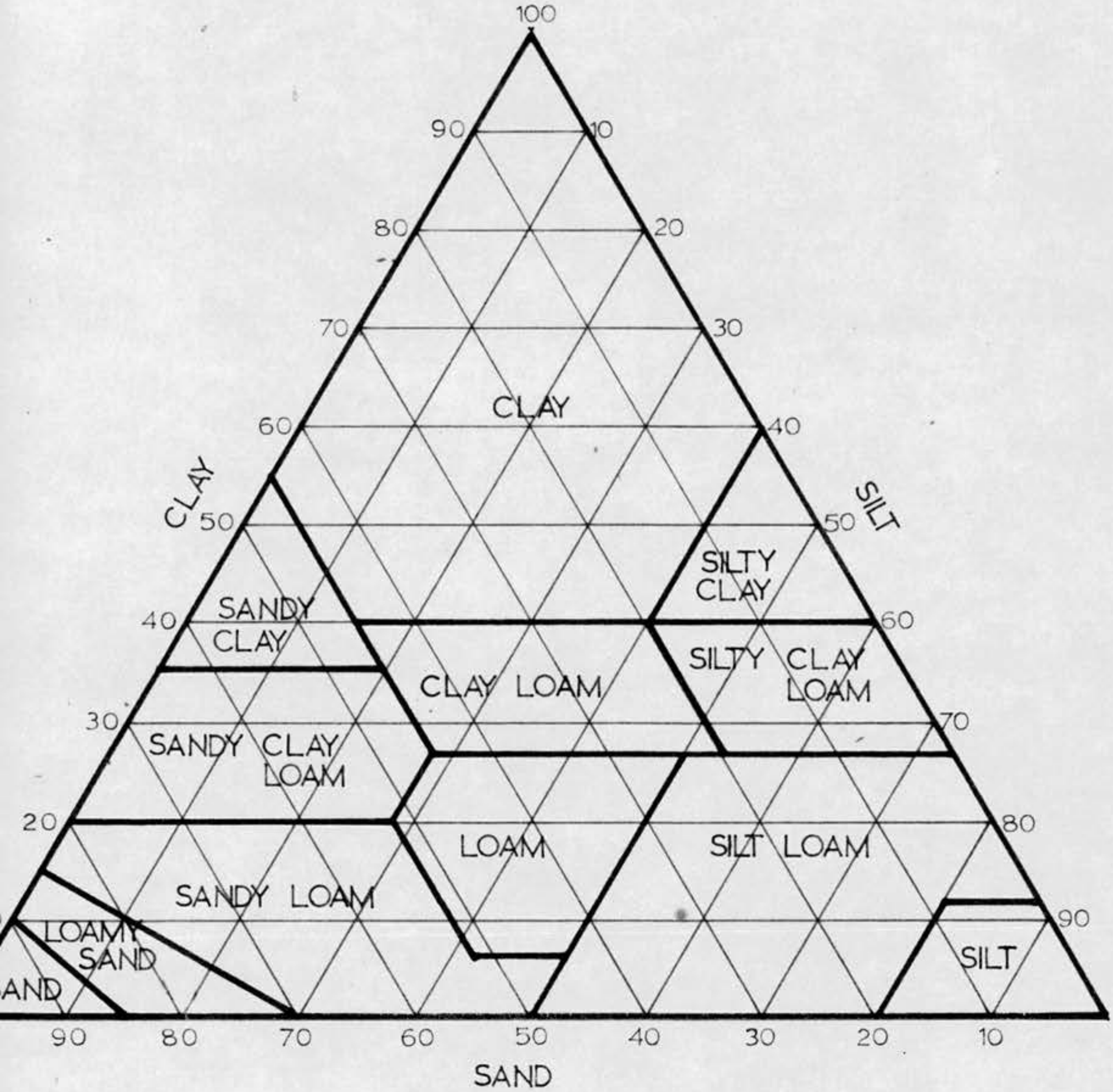
coarse textured soils' were now called 'FARIDA'. These soil names are the place names where that particular group of soil is in preponderance. Table 30 shows areas under each of these soil groups.

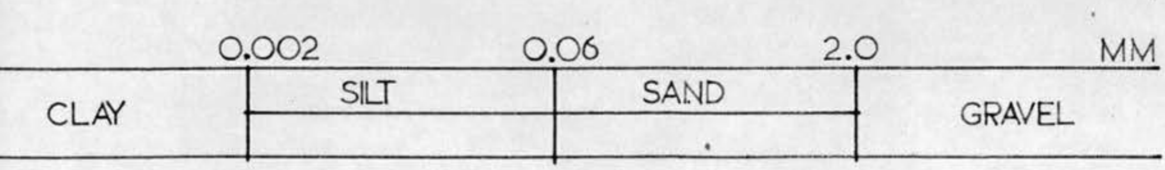
Detailed soil maps, as described in Part IV, are later drawn based on these groupings.

TABLE 29 GENERAL GROUPINGS

Soil Group	Basic soil texture name	Composition % clay	% silt	% sand	Soil Group	
SANDY SOILS						
1. Coarse textured soils	Sand	0-10	0-15	85-100	A	JHANG
	Loamy sand	0-15	0-30	70-85	B	
2. Moderately coarse textured soils	Sandy loam	0-20	0-50	43-70	A	FARIDA
	Fine sandy loam	0-20	0-50	43-70	B	
LOAMY SOILS						
3. Medium textured soils	Loam	7-27	28-50	23-52	A	
	Silt loam	0-27	50-80	0-50	B	BUCHIANA
	Silt	0-12	80-100	0-20	C	
4. Moderately fine textured soils	Clay loam	27-40	15-52	20-45	A	
	Sandy clay loam	20-35	20-28	45-80	B	CHUHARKANA
	Silt clay loam	27-40	40-73	0-20	C	
CLAY SOILS						
5. Fine textured soils	Sandy clay	35-55	0-20	45-65	A	
	Silt clay	40-60	40-60	0-20	B	NOKHAR
	Clay	40-100	0-40	0-45	C	

4 TEXTURAL CLASSIFICATION DIAGRAM





PARTICLE SIZE LIMITS

TABLE 30 SOIL CLASSIFICATION

(Area in acres)

	Name of the area	Total area	Jhang Group	Farida Group	Buchiana Group	Churharkana Group	Nokhar Group
	(a) Rachena Doab						
1.	Chickoki-Mallian and Shadman	1,60,000	4,800	32,000	1,16,000	7,200	-
2.	Shakhot	2,47,200	24,700	1,65,600	43,300	13,600	-
3.	Chuharkana	10,800	200	2,900	5,000	2,600	100
4.	Pindi Bhattian	8,300	5,700	1,300	1,200	100	-
5.	Khanqah Dogran	1,21,800	21,900	52,400	39,000	8,500	-
6.	Jaranwala	90,000	10,900	64,400	15,300	300	-
7.	Hafizabad Thatta	1,31,300	18,700	61,500	46,500	4,600	-
8.	Harse Sheikh	1,15,400	35,900	39,200	39,400	900	-
9.	Sangla Hill	1,50,700	28,600	39,900	76,000	6,200	-
10.	Beranwala	1,25,900	800	54,200	63,400	7,500	-
11.	Zafarwal	2,04,200	12,800	85,800	91,900	13,300	1,000
	Sub Total	13,66,500	1,64,400	5,99,200	5,37,000	64,800	1,100
	(b) Chaj Doab						
12.	Lalian	1,98,000	31,500	46,400	1,05,500	13,200	1,400
13.	Maggowal	35,400	2,300	7,100	12,500	21,200	2,300
	Sub Total	2,33,400	33,800	53,500	1,18,000	34,400	3,700
	(c) Thal Doab						
14.	Muzaffargarh	98,500	7,500	53,600	12,500	14,800	1,100
15.	Area of Lower Thal excluding Muzaffargarh	12,00,500	4,16,500	3,81,400	3,46,500	-	46,100
	Grand Total	28,99,900	6,22,200	10,87,700	10,14,000	114,000	52,000
	Percentage of total	100	21.53	37.65	35.12	3.91	1.79

CHAPTER 5

THE SOILS ON BELIANWALA SITE

This chapter gives a brief resume of the tests used in the classification of the soils, as carried out in the previous chapter, with reference to a particular site in the area. Detailed descriptions of these tests are avoided because they are given in the standards to which reference is made in each case.

5.1 GRANULOMETRIC ANALYSIS

This system determines the basic soil components by measuring the size of the particles within a given range by mechanical means. It is based on the assumption that a soil material may be sub-divided into fractions according to the size of the constituent particles. Various research organizations establish the upper and lower limits of such fractions rather arbitrarily within which the range of particle size exhibits standard engineering functional quality. The main distribution of such arbitrary limits under the US Department of Agriculture scale are shown at the bottom of Fig.4.

The mechanical analysis is a series of operations to which soil is subjected. Material retained on $\frac{3}{4}$" (20 mm) round hole sieve cannot be analysed in this system. The test procedures are described in B.S.1377 (1967).[1] It is difficult to make a granulometric analysis of the fine soil particles by using sieves. For this reason the fine material is usually tested in the laboratory by methods of wet analysis based

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1. BRITISH STANDARDS INSTITUTION, "Methods of Testing Soils for Civil Engineering Purposes", Test 7, 'Determination of Particle Size Distribution', B.S.1377 (1967), p.55.

principally on the speed of sedimentation. The finer the particle, the more time it requires to settle through a certain distance. The test described in B.S.1377 for fine grained soils was used for this purpose.[1]

The results of a mechanical analysis are usually represented graphically in the form of a particle size distribution curve. The abscissa of this curve are diameters of particles plotted on a logarithmic scale and corresponding ordinates show on a normal scale the percentage of particles finer than a given equivalent diameter.[2]

5.2 STATES OF CONSISTENCY

The cohesive character of a soil depends mainly on the clay content, therefore when dealing with a soil it is very important to know not only its granular composition but also certain physical properties of the material made up of fine particles. Clays vary greatly in their physical and chemical characteristics, apart from actual particle size, and owing to the extremely fine size it is very difficult to investigate their properties. For the purpose of soil stabilization the characteristics of a clay may be usefully expressed in terms of its states of consistency.

Soils may assume various states, between the extremes of solidity and liquidity, according to changes in their moisture content. For instance if a cohesive soil is immersed in water it will disintegrate and in the presence of a sufficient quantity of water it may be transformed into a viscous liquid by stirring it well. It is then said

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1. BRITISH STANDARDS INSTITUTION, "Methods of Testing Soils for Civil Engineering Purposes", Test 7(C), 'Standard Method for Fine Grained Soils', B.S.1377, p.61.

2. See Fig.5 in Chapter 6.

to be in the liquid state (first state of consistency). Upon drying the mass becomes denser and stiffer and at a certain moisture content termed 'liquid limit' loses its capacity to flow as a liquid but can be readily moulded and holds its shape. The mass is now in the 'plastic state' (second state of consistency). Upon further loss of moisture the plastic properties are lost, and at a certain moisture content termed 'plastic limit' the soil crumbles when worked. This is the semi-solid state (third state). If the process of evaporation continues the soil mass passes gradually from the semi-solid to the hard solid state (fourth state). The limit between semi-solid and solid state is the 'shrinkage limit'. An outline of possible states of a cohesive soil may be tabulated as follows:

TABLE 31 STATES OF CONSISTENCY

States of cohesive soil	Limits between the states
1. Liquid	
	Liquid limit[1]
2. Plastic	
	Plastic limit[2]
3. Semi-solid	
	Shrinkage limit[3]
4. Solid	

1. 'Determination of liquid limit', B.S.1377 (1967), p.33.
2. 'Determination of plastic limit', B.S.1377 (1967), p.42.
3. 'Determination of linear shrinkage', B.S.1377 (1967), p.45.

Cohesive soils can also be conveniently shown on a plasticity chart.[1] On this chart the plasticity index is plotted against the liquid limit. It is possible to predict to a certain extent the behaviour in the field of a certain soil by the help of this chart. For instance a sandy loam soil absorbs a comparatively small amount of moisture, dries out quickly, and is practically non-plastic. The plasticity index of such a soil is low. On the other hand a clay or loam soil readily absorbs moisture, dries out slowly and is plastic. A high liquid limit and a high plasticity index show that a soil has a great affinity for water. Correspondingly it will have a marked tendency to volumetric change through change in external moisture conditions. Such a soil will be more difficult to stabilize than one with a low liquid limit and low plasticity index. It will also be more difficult to mix with cement.

5.3 ORGANIC MATTER

The surface layer of almost all soils contained organic material and it would be prudent in nearly every case to discard the surface layer. In most cases removal of up to 12" of surface layer was sufficient to ensure freedom from organic matter, but in certain localities particularly in villages near the rivers, there may be beds of recently deposited surface. It is therefore desirable to carry out a test for organic impurities when the magnitude of the project requires this and the facilities are available. The standard test for organic matter is described in B.S.1377.[2]

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1. CASAGRANDE, A., "Classification and Identification of Soils", Proceedings of the American Society of Civil Engineers, 1947, pp.783-810.
2. BRITISH STANDARDS INSTITUTION, B.S.1377 (1967), Test 8, p.86.

5.4 SOIL REACTION

Soil reaction receives special emphasis in soil identification, because it gives an indication of other soil qualities less easily determined directly. The intensity of soil acidity or alkalinity is expressed in P^H. With this notation $P^H 7$ is neutral, lower values indicate acidity, and higher values show alkalinity. The P^H of the soil horizons in the area surveyed varied between 7.1-10.2 but it is possible to find soils with P^H as low as 3.5. The corresponding terms used for ranges in P^H are as follows:

TABLE 32 SOIL REACTION

Terminology	P^H range
Extremely acid	below 4.5
Very strongly acid	4.5 - 5.0
Strongly acid	5.1 - 5.5
Moderately acid	5.6 - 6.0
Slightly acid	6.1 - 6.5
Neutral	6.6 - 7.3
Mildly alkaline	7.4 - 7.8
Moderately alkaline	7.9 - 8.4
Strongly alkaline	8.5 - 9.0
Very strongly alkaline	above 9.1

Soils rich in clay or in organic matter were found to have greater reserves of acidity or alkalinity than sandy soils or those low in organic matter. A P^H value much above usually indicated the presence of some free carbonates but not always. It has been shown, based on the relation between the P^H of the soil and the seven-day compressive strength of the stabilized soil, that a large difference in behaviour of alkali and acid soils exists. Alkali soils (P^H greater than 7) proved to be far more suitable for stabilization than acid soils (P^H less than 7) in this study carried out on UK soils.[1]

The colorimetric method was used for the determination of P^H.[2]

5.5 SALT CONTENT

Determination of the sulphate content of the natural soil and sulphate content of ground water was made using the standard method given in B.S.1377.[2] The method involves preparation of an aqueous extract of the soil since all salts concerned are sufficiently soluble in water for the purpose.

5.6 WATER TABLE

The water table was measured from the holes initially bored for the purpose of obtaining soil samples. The hole was left for about 24 hours for the water to rise to its final level. The level was usually measured by lowering a weighted tape until its lower end just touched the water surface. In some cases where water level was high enough it could also be measured by a ranging rod.

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1. SHERWOOD, P.T., "The Effect of soil organic matter on the setting of soil cement mixtures", Road Research Laboratory, UK, 1962.
2. 'Determination of the P^H value', B.S.1377 (1967), p.103.
3. 'Determination of the sulphate content of soil and sulphate content of ground water', B.S.1377 (1967), p.90.

~~into the hole~~. Under certain conditions boring sometimes disturbed a zone of more than usually permeable soil in which rapid flow was taking place. In ~~both~~ these circumstances another hole nearby was put down as a check.

CONCLUSIONS TO PART II

(Refer to Part IV)

A review of some of the soil problems such as waterlogging and salinity in some areas, followed by an extensive soil survey in Thal area revealed some interesting facts which may be summarized as below and are embodied in graphic form in the concluding part of this study.

a) Almost the entire Indus Basin is a flat stretch of thousands of square miles with very gentle slope towards the Arabian Sea. This vast plain seems to offer itself for extensive exploitation not only in the use of the soil resources but also in the application of mass housing techniques based in principle on road making procedures, for which level and unobstructed sites may be an important prerequisite.

b) The ground water table in certain areas may be too near the surface to be desirable from the point of view of attaining optimum moisture conditions in the soil for subsequent compaction. This however does not generally present a significant problem because water table in very few areas has reached above ten feet from the ground surface which may be taken as an arbitrary criterion in absence of any information on this particular question. This limit is suggested based on the determination of natural moisture content, which up to this level was found to be still lower than the optimum moisture of compaction.[1]

c) Accumulated salts both from within the soils and due to canal water in the soils of some areas is another danger to be guarded against. The presence of salts is quite often detectable visually apart from

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1. The significance of this factor will be discussed in Chapter 9.

laboratory tests. Stabilization in areas severely affected by salinity is not recommended until more is known about the effect of salts on the stabilization of soils with cement.

d) The occurrence of any particular range of soil was generally large enough to be plotted on a reasonable scale and be used for future reference and planning purposes. Frequent changes in the soil texture over small areas were rare and where such patches did occur they could generally be identified visually as well due to changes in physical features.

e) The soils generally were reasonably well graded mixtures of sands, silts and clays which later gave good results due to finer particles packing the voids in the coarser particles. Soils composed solely of any one of the textural elements alone were rare and occurred in isolated and easily recognisable profiles. It would therefore be possible in almost every case to use the soil from the site itself for house building purposes. Only in rare cases it may be necessary to mix it with the deficient constituent from a nearby site.

PART III

DETERMINING THE SUITABILITY

OF THE RESOURCES

CHAPTER 6

THE SOIL REQUIREMENTS

The whole structure of stabilization rests on the suitability of the soils in that particular area. No doubt it is possible to stabilize almost any soil, but the objective is not to establish the theory of stabilization but to find the feasibility of a practical application of the soil resources identified and located in the previous chapters. A programme of laboratory experimentation was therefore devised to help determine suitability criteria of each of the major soil groups by subjecting their stabilized specimens to durability tests.

6.1 SOIL IN STABILIZATION

The behaviour of soil when stabilized with Portland cement is determined by various constituents in its composition each imparting its properties to the final product in its own way. The ultimate influence on the final product is therefore dictated by the proportion of these constituents in the soil. The effect of each of its components is briefly reviewed below.

6.1.1 Gravel and Coarse Sand

These supply frictional resistance and give structural strength to the mixture. These fractions do not exhibit cohesion, plasticity or colloidal properties and therefore are called chemically inert.

6.1.2 Fine Sand

This serves to fill the voids between coarser material and is also chemically inert.

6.1.3 Silt

This size of material is useful in filling the voids and also provides a small degree of frictional resistance. It has slight cohesion which is of a temporary nature. This cohesion is caused by the presence of minute water films which enables very close packing of the particles.

6.1.4 Clay

Clay has practically no frictional resistance but gives strength by its considerable cohesiveness due to intermolecular forces and moisture films.

6.1.5 Colloidal Clay

The particles of a part of the clay content are so small that the adsorbed layers of moisture affect the properties of the material; that part of the clay content is then said to be in Colloidal State. The upper limit in particle size coincides with the limit of clay particles i.e. .002 mm. These colloidal particles are responsible for the particles not coalescing into larger grains which means that clay in bulk is a collection of very small particles in fluid medium which results in a very plastic material.[1]

6.2 TESTS FOR SUITABILITY

6.2.1 Obtaining Soil Samples

Samples were obtained from the selected locations representing each soil group. A conscious effort was made to ensure that the results

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1. ARMITAGE, J.S., "Chemical Pretreatment for Soil Stabilization", M.Sc. Thesis, Leeds, 1959.

of this investigation represent not merely the best but all variations of soil composition within a major soil group. It therefore needs to be emphasized that the results obtainable in most areas should be far more optimistic than what this study represents.

The natural moisture content in each case was determined immediately after the soil was taken from the bore hole.[1]

6.2.2 Determining Optimum Moisture Content

Samples of soil were sealed and brought to Belianwala site laboratory for testing. The samples were prepared by standard method which involved drying and pulverizing.[2] Drying of the samples was carried out by spreading the soils in different trays and allowing to dry in the air at room temperature for four days. B.S.1377 allows if necessary drying in oven at temperatures up to 110°C, but oven drying of samples was not necessary due to high air temperatures. It was also not recommended by the soil chemist advising in laboratory experimentation on the ground that some soils particularly those containing much organic matter and some heavy clays would undergo irreversible changes. The dried samples were ground by means of a rubber-covered pestle so as to break the soil aggregates without crushing the individual particles.

Optimum moisture of each sample was obtained using standard method.[3]

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1. B.S.1377, Determination of the moisture content, sun bath method, p.28.
2. B.S.1377, Preparation of disturbed samples for testing, p.15.
3. BRITISH STANDARDS INSTITUTION, "Methods of Test for Stabilized Soils", Test 4, 'Determination of the Dry Density/Moisture Content Relationship', B.S.1924 (1957), p.32.

6.2.3 Preparing Stabilized Soil Specimens

Prepared soil samples representing each soil group were mixed with varying amounts of cement and moisture contents. Each specimen was compacted by the standard method at its optimum moisture content (without cement as determined previously), at moisture content slightly below and above the optimum. The specimens were cured for 28 days in a moist room.

6.2.4 Testing for Suitability

The standard tests available for determining the resistance of stabilized soil to the destructive forces of weather were developed originally to simulate the weathering of this material as used in roads and airfield construction. The limitations or in some cases the severities of these tests for building purposes must be recognised.[1] A brief evaluation of the tests carried out is given below.

6.2.4.1 Dry density. A consistent relationship between density (weight of dry soil per cubic foot) and mechanical analysis of a soil has been shown to exist.[2] In fact variation in texture and grading is so accurately reflected in the compacted density that a routine density test may be the most practical basis for designing the stabilized earth mixtures. A further fundamental advantage of the test which measures compacted density lies in the fact that it directly measures the total

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1. For an evaluation of different durability tests see: RANSOM, W.H., "Soil Stabilization: A Review of Principles of Practice", Department of Scientific and Industrial Research, Building Research Station, Tropical Building Studies Number Five 1963.

2. HOUSEL, W.S., "Experimental Soil-Cement Stabilization at Cheboygan", Michigan, USA.

voids which later may serve as the basis of determining the required cement content. Density of the stabilized soil specimens was considered to constitute an important criterion of the compaction obtained and provided an indication of their strength and durability.

The standard B.S. test was used for the purpose.[1]

6.2.4.2 Compressive strength. Compressive strength of most unstabilized soils may be above normal requirements, yet this test was used because it has been shown to be an important indicator of the durability of the specimens.[2]

Standard method described in B.S.1924 was adopted.

6.2.4.3 Volume change. Recent work in the field has shown that dimensional change measurements are a very sensitive direct measure of deterioration. The amount of shrinkage on drying depends more on soil type and less on cement content. Other deteriorating effects such as sulphate attack, alkali reactivity and stress due to differential thermal co-efficients are also easily detected in volume change measurements.

Volume change in compacted stabilized soil specimens occurs in the shape of initial drying shrinkage and subsequent expansion when a dried specimen is wetted. The expansion occurring in the latter case is much less than the initial drying shrinkage (of the order of one-third to one-half).[3] The specimens were therefore tested for initial drying shrinkage only.

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1. B.S.1924, Determination of dry density, p.32.
2. HIGHWAY RESEARCH BOARD , "Standard Laboratory Tests for Soil-Cement", by Norling, L.T., Research Record No.36.
3. SOUTH AFRICAN COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH, "The properties of compacted soil and soil-cement mixtures for use in building", by Webb, T.L., and Cilliers, T.F., Pretoria, March 1957, p.13.

The method used involved immersing the specimen in mercury immediately after compaction and thereafter drying it in a thermostatically controlled oven at 105°C.

6.2.4.4 Weathering. Retention of stability over years of exposure to the destructive forces of weather should be the primary criterion of the suitability of the building material under consideration. Weathering of the material in actual construction is a slow process spread over years, therefore a relation between the results of the available laboratory tests and the actual weathering of the material in the field is not easy to establish. Some attempts have been made in this direction by trying to use tests which simulate actual field conditions as closely as possible e.g. spraying the face of the specimen or wall with water at a controlled pressure.[1]

A criterion of weathering for each region when developed would have to be based on the exposure conditions (a product of average annual rainfall and annual average wind speed) of that particular area.[2]

The test adopted is intended to provide a basis of comparison only because a rigid weight loss criterion, under the present state of knowledge on the subject, could not be adopted. The comparison of the results with those of the burnt clay brick, however, gives these results a practical standing.

The test used as ASTM D.59(57) which involves compacting specimens as described earlier, curing for seven days in a moist room and then

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1. HOUSING AND HOME FINANCE AGENCY, "Earth for Homes", Ideas and Methods Exchange No.22, Washington, 1955.

2. BUILDING RESEARCH STATION (UK), "An Index of Exposure to Driving Rain", Building Research Station Digest 23 (Second Series).

submerging in water for five hours at room temperature.[1] They were then dried for 42 hours at 71°C (160°F), weighed and given two firm strokes with a wire scratch brush on all its surfaces. Twelve such cycles were repeated unless the specimen disintegrated earlier. The weight loss was expressed as percentage of the original dry weight.

6.3 DETERMINING THE SOIL REQUIREMENTS

Suitability of a particular soil or in other words the type of soil required for effective stabilization can be determined only after the results of various tests applied are analysed taking each variable (i.e. cement and moisture) into consideration. It is intended to discuss the influence of each variable separately for the purposes of clarity. Conclusions about the collective influence of these variables can later be derived based on this primary analysis. Table 33 gives an analysis of soils under investigation and Fig.5 records their particle size distribution in graphic form. Results of this investigation are given in Table 34. The effects of each of the variables on tests performed for durability are examined in this part of the study. The effects of soil type on stabilization as reflected in the tests are the subject of investigation in this section.

6.3.1 Dry Density

The nature of the soil has been shown to have a marked bearing on the densities attained. Air dry densities decreased sharply for soils containing more clay. Well graded soils attained higher densities due to close packing of the voids in coarser material by finer material. Sandy soils (Farida group) with just enough clay to bind the sand particles together gave highest densities (see Fig.6).

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1. AMERICAN SOCIETY FOR TESTING MATERIALS, Standard Method of Test for Durability, ASTM, D.59(57).

6.3.2 Compressive Strength

Compressive strength like dry density was seen to be related to the nature of the soil. Well graded soils gave higher compressive strength. Type of the clay present (due to interaction with cement) was expected to have some unpredictable effects on the compressive strength but no marked reduction of this strength due to this factor alone could be traced in the results (see Fig.7).

6.3.3 Volumetric Shrinkage

Generally smaller volumetric shrinkage occurred where clay content was less. Jhang group showed least volumetric shrinkage though inferior in other respects. Churkana group showed a slight deviation in the general rule stated above insofar as it had greater volumetric shrinkage as compared with Nokhar whose clay content was larger (see Fig.8).

6.3.4 Weight Loss

Amongst many others factors influencing the weight loss in the specimens, the soil type appeared to be the most important.[1] Other factors being equal, clay soils indicated considerably greater weight loss as compared with sandy soils (see Fig.9).

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1. These factors i.e. moisture of compaction and the cement content are investigated in the chapters that follow.

TABLE 33 ANALYSIS OF THE SOIL SAMPLES INVESTIGATED FOR DURABILITY

Soil Series	Soil Type	Basic soil texture	USDA soil texture range			Actual mechanical composition			States of consistency			Natural M.C. in sample	Soil O.M.C.	Name of the site
			Clay	Silt	Sand	Clay	Silt	Sand*	L.L.	P.L.	P.I.			
1. JHANG	Coarse textured	Loamy sand	0-15	0-30	70-85	4	26	70	22	17	5	2	11	DHER
2. FARIDA	Moderately coarse textured	Sandy loam	0-20	0-50	43-70	15	35	50	25	17	8	4	13	BELIANWALA
3. BUCHINA	Medium textured	Silt loam	0-27	50-80	0-50	19	57	24	27	16	10	3	14	SHER SHAH
4. CHURKANA	Moderately fine textured	Silt clay	27-40	40-73	0-20	31	58	11	43	22	21	4	15	ALI KHEL
5. NOKHAR	Fine textured	Sandy clay	35-55	0-20	45-65	48	7	45	33	18	15	2	17	MOLVI WALA

* Small percentages of particles up to $\frac{1}{4}$" diameter are also included in this column.

FIG. 5 PARTICLE SIZE DISTRIBUTION CURVES FOR SOILS

NO.	SOIL GROUP	CLAY	SILT	SAND
1	JHANG	4	25	70
2	FARIDA	15	35	50
3	BUCHINA	19	57	24
4	CHURKANA	31	58	11
5	NOKHAR	48	7	45

TABLE 34 RESULTS OF DURABILITY TESTING

1. JHANG																		
Cement (%)	0	0	0	1	1	1	2	2	2	4	4	4	6	6	6	8	8	8
Moisture (%)	9	11	13	9	11	13	9	11	13	9	11	13	9	11	13	9	11	13
Density(lbs/c.ft)	107.2	108.4	107.8	109.3	110.7	109.5	111	112	110.4	113.4	114	113.5	114.5	115.7	114.6	114.8	116.6	115.5
Comp.strength (lbs./sq.inch)	275	363	327	447	562	454	594	669	562	784	821	795	878	975	897	903	1052	964
V.shrinkage (%)		.94			.82			.71			.60			.54			.52	
Weight loss (12 cycles)		Disintegrated			15.3			8.1			5.7			3.8			1.5	
2. FARIDA																		
Cement	0	0	0	1	1	1	2	2	2	4	4	4	6	6	6	8	8	8
Moisture	11	13	15	11	13	15	11	13	15	11	13	15	11	13	15	11	13	15
Density	110.8	111.6	110.5	113.4	114.5	112.7	115.4	116.3	115	117.3	119.3	118	119.1	120.7	118.8	121.3	124.1	123.1
Strength	563	639	543	791	874	725	957	1027	923	1107	1255	1186	1251	1392	1217	1414	1589	1531
Shrinkage		1.23			1.08			.92			.71			.60			.53	
Weight loss (12 cycles)		Disintegrated			9.2			4.8			3.2			2.1			0.8	
3. BUCHINA																		
Cement	0	0	0	1	1	1	2	2	2	4	4	4	6	6	6	8	8	8
Moisture	12	14	16	12	14	16	12	14	16	12	14	16	12	14	16	12	14	16
Density	109.6	110.4	109.2	111.2	111.4	110.9	112	112.8	111.7	115.8	116.3	115.7	118.2	118.9	119.1	119.4	120	119.3
Strength	487	521	465	610	638	592	683	732	657	991	1012	973	1188	1229	1257	1275	1331	1264
Shrinkage		.61			.35			1.10			.83			.68			.62	
Weight loss (12 cycles)		Disintegrated			13.7			6.1			4.4			3.2			1.1	

4. CHURKANA

Cement	0	0	0	1	1	1	2	2	2	4	4	4	6	6	6	8	8	8
Moisture	13	15	17	13	15	17	13	15	17	13	15	17	13	15	17	13	15	17
Density	107.8	109.2	107.5	108.4	109.5	107.7	109.9	110.9	110.9	110.5	112.5	110.8	112.4	113.7	112.8	114	115.8	114.4
Strength	329	417	322	382	445	311	452	583	433	552	612	562	705	812	735	851	985	863
Shrinkage		2.54			2.25			2.00			1.65			1.48			1.40	
Weight loss (12 cycles)		Disintegrated			Disintegrated			13.4			5.8			4.5			2.9	

5. NOKHAR

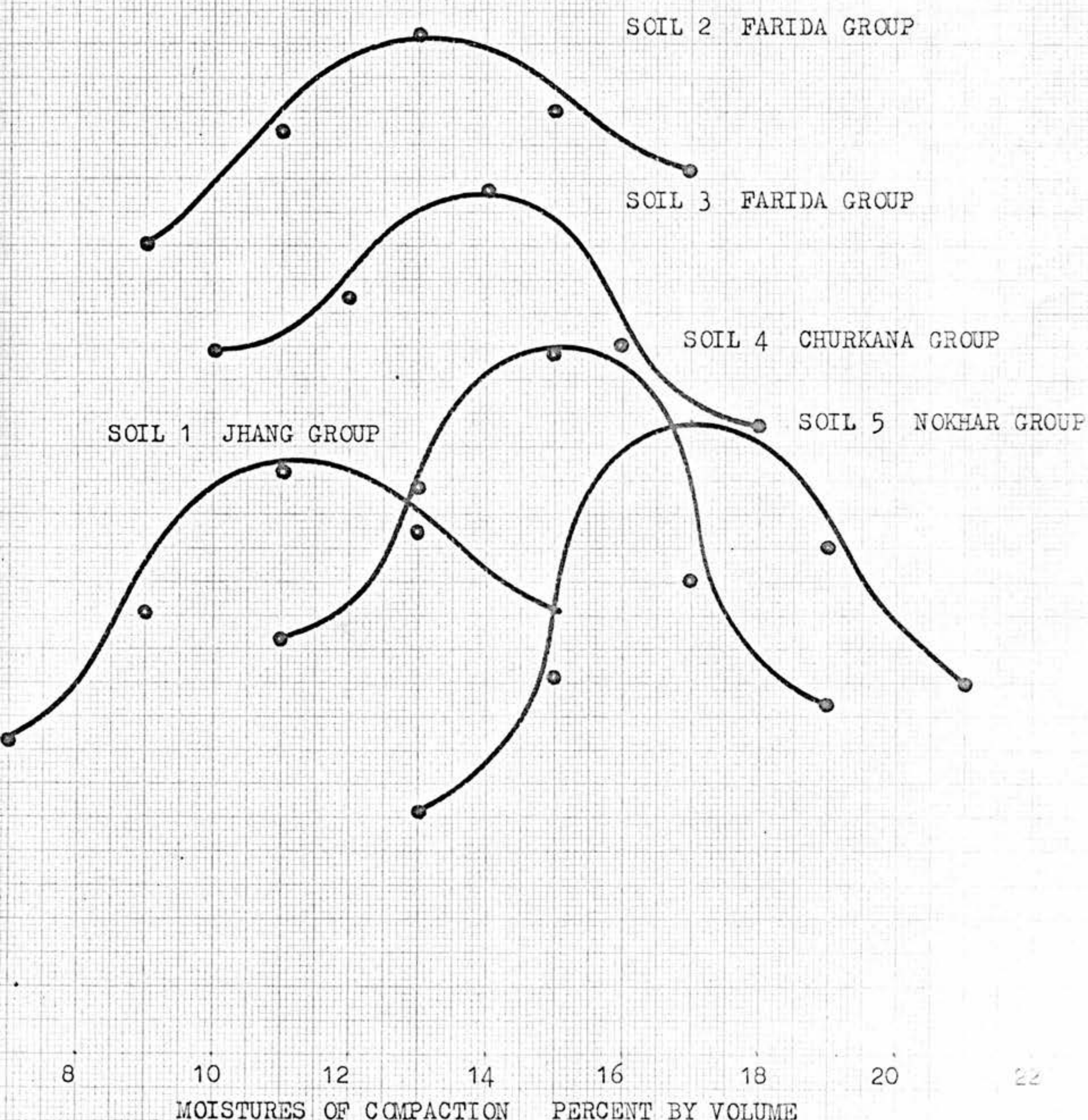
Cement	0	0	0	1	1	1	2	2	2	4	4	4	6	6	6	8	8	8
Moisture	15	17	19	15	17	19	15	17	19	15	17	19	15	17	19	15	17	19
Density	106.8	108.7	107.8	107	109	107.5	108.5	109.8	108.2	108.8	111.4	109.5	111.5	113.3	111	112.7	114.2	113
Strength	247	393	361	249	335	307	375	483	352	401	610	575	623	772	604	722	851	765
Shrinkage		2.51			2.10			1.88			1.50			1.24			1.13	
Weight loss (12 cycles)		Disintegrated			Disintegrated			11.3			7.4			6.7			4.2	

FIG. 6 EFFECT OF SOIL TYPE ON DRY DENSITY

DETERMINATION OF OPTIMUM MOISTURES
OF COMPACTION

(DRY DENSITY/MOISTURE CONTENT RELATIONSHIPS)

ALL SOILS WITHOUT ANY CEMENT CONTENT



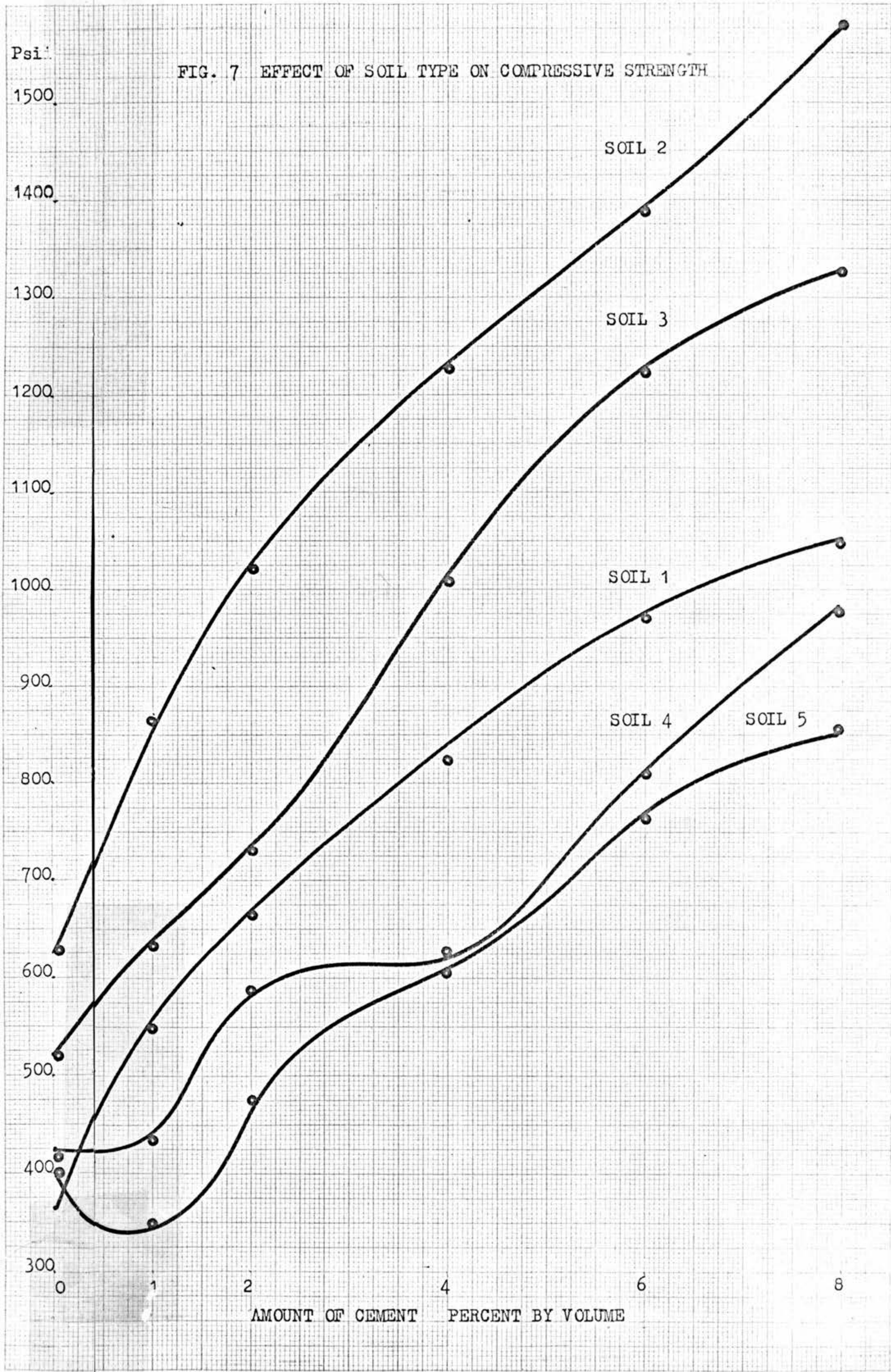


FIG. 7 EFFECT OF SOIL TYPE ON COMPRESSIVE STRENGTH
Psi
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
SOIL 2
SOIL 3
SOIL 1
SOIL 4
SOIL 5
0
1
2
4
6
8
AMOUNT OF CEMENT PERCENT BY VOLUME

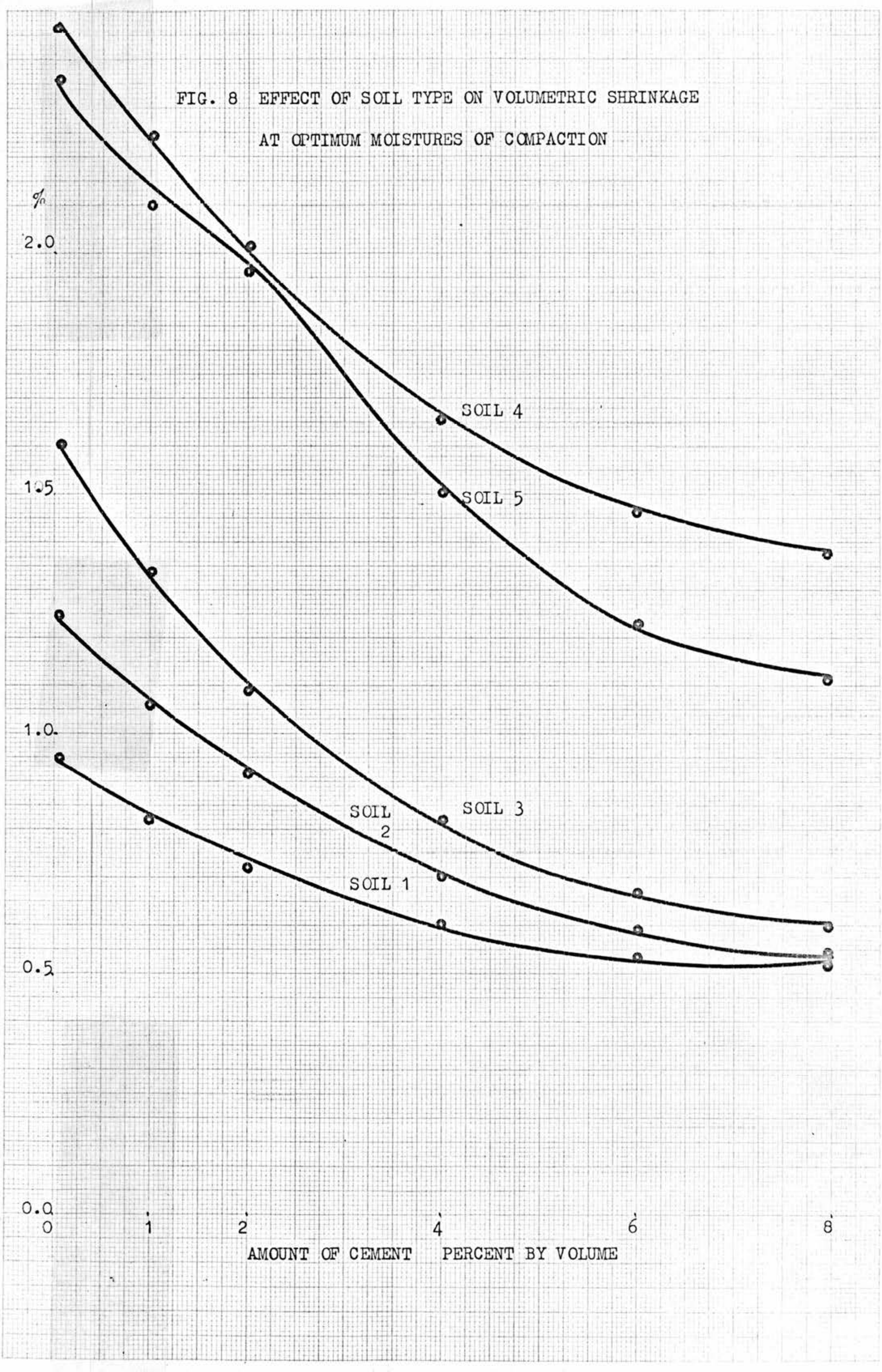
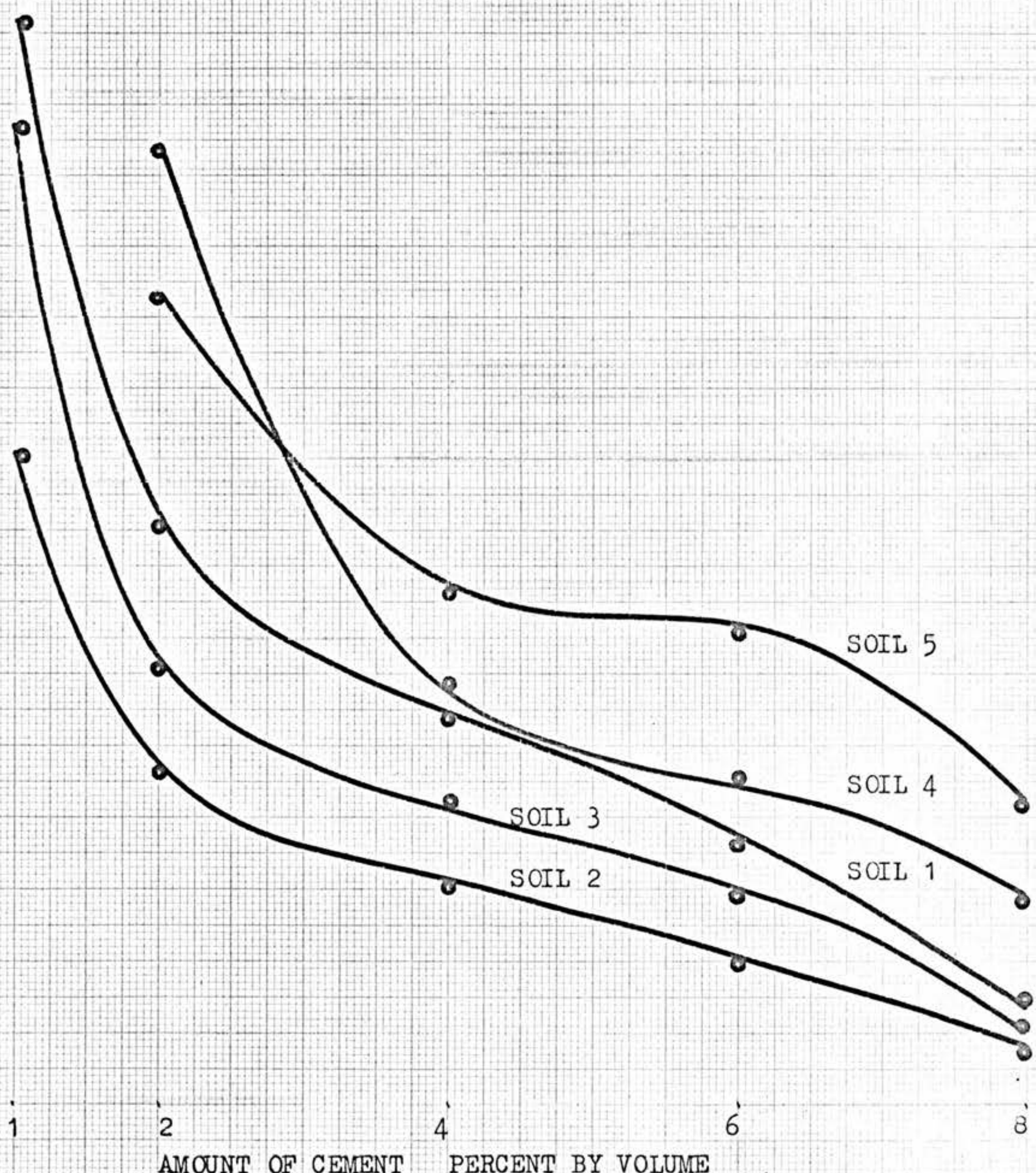


FIG. 8 EFFECT OF SOIL TYPE ON VOLUMETRIC SHRINKAGE
AT OPTIMUM MOISTURES OF COMPACTION
%
2.0
1.5
1.0
0.5
0.0
0
1
2
4
6
8
SOIL 4
SOIL 5
SOIL 3
SOIL 2
SOIL 1
AMOUNT OF CEMENT PERCENT BY VOLUME

FIG. 9 EFFECT OF SOIL TYPE ON WEIGHT LOSS

AT OPTIMUM MOISTURES OF COMPACTION



CHAPTER 7

THE CEMENT REQUIREMENTS

The improvement in the engineering properties of soils stabilized with cement is believed to be due mainly to the hardening of Portland cement but the processes taking place during the hydration of cement in the presence of clays are not yet fully understood. All soil groups under investigation showed favourable response to the addition of cement but to varying degree. This chapter intends to help find a minimum cement requirement for each soil for the kind of results desired.

7.1 CEMENT IN STABILIZATION

Considerable attention is being given to establish a clearer understanding of the soil cement interaction.[1] It cannot be overemphasized that upon a better understanding of this aspect depends, to a great extent, the future of this unique material.

If the hardening of soil cement were due solely to the hydration of cement, the soil could be regarded as a chemically inert component. The cement particles would bind adjacent soil grains together during hardening and form a more or less continuous skeleton of a hard strong material enclosing a matrix of unaltered soil. This skeleton could also be expected to plug some of the voids of the soil reducing permeability and swelling and increasing the resistance of soil cement to the deleterious effects of changes in subsequent moisture conditions. Several recent investigations have however shown that in addition to

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1. An active investigation of this aspect is being carried out by the Portland Cement Association in their Research and Development Laboratories, Skokie, Illinois, USA.

hardening, reactions take place between hydrating cement and clay components generating additional cementitious material leading to the strengthening of the bonds between the soil grains themselves and between soil and cement particles. At the same time clay participating in such reactions could suffer alteration to the extent that it would become less expansive when exposed to water.[1,2]

7.2 DETERMINING THE CEMENT REQUIREMENTS

The optimum amount of cement required can be determined by examining the effect of the varying amounts of cement on each of the standard tests.

7.2.1 Dry Density

A gradual increase in dry density with increase in amount of cement was noticed. Some slight additions of cement at initial stages produced greater changes in density than at higher cement contents, as seen in the curves which become more flat as they proceed towards higher cement contents (see Figs.10-14).

7.2.2 Compressive Strength

Considerable gains in compressive strength were recorded with small amounts of cement over specimens containing no cement. The rate of increase in strength with increasing cement contents was generally uniform though some exceptions were noticed. An example of this was

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1. HANDY, R.L., "Cementation of Soil Minerals with Portland Cement or Alkalies", Highway Research Board (USA) Bulletin 241 (1960), pp.67-108.

2. CATTON, M.D., "Research on Physical Relations of soils and soil cement Mixtures," Highway Research Board Proceedings 20 (1940), pp.821-55.

heavy clay soil (Nokhar) where initial 1 percent addition of cement produced slight decrease in strength but this trend was quickly reversed on further additions of small amounts of cement. This phenomenon could be attributed to the characteristics of the particular type of clay present in the samples representative of that group. Small variations in strength due to this factor could be expected in almost any group. (See Figs.15-19).

7.2.3 Volumetric Shrinkage

A decrease in volumetric shrinkage was noticed in the case of each soil group though the rate of decrease varied significantly in certain cases. Minimum ultimate volumetric shrinkage with 4 percent cement was achieved with Jhang group which incidentally also had the lowest value even without any addition of cement. (See Figs.20-24).

7.2.4 Weight Loss

All specimens without any cement content disintegrated during five hours of submergence in water. Very significant improvements were recorded in case of each group but the most outstanding rate was shown by Farida. (See Figs.25-29).

FIG. 10 EFFECT OF CEMENT CONTENT ON DRY DENSITY

SOIL 1. JHANG GROUP

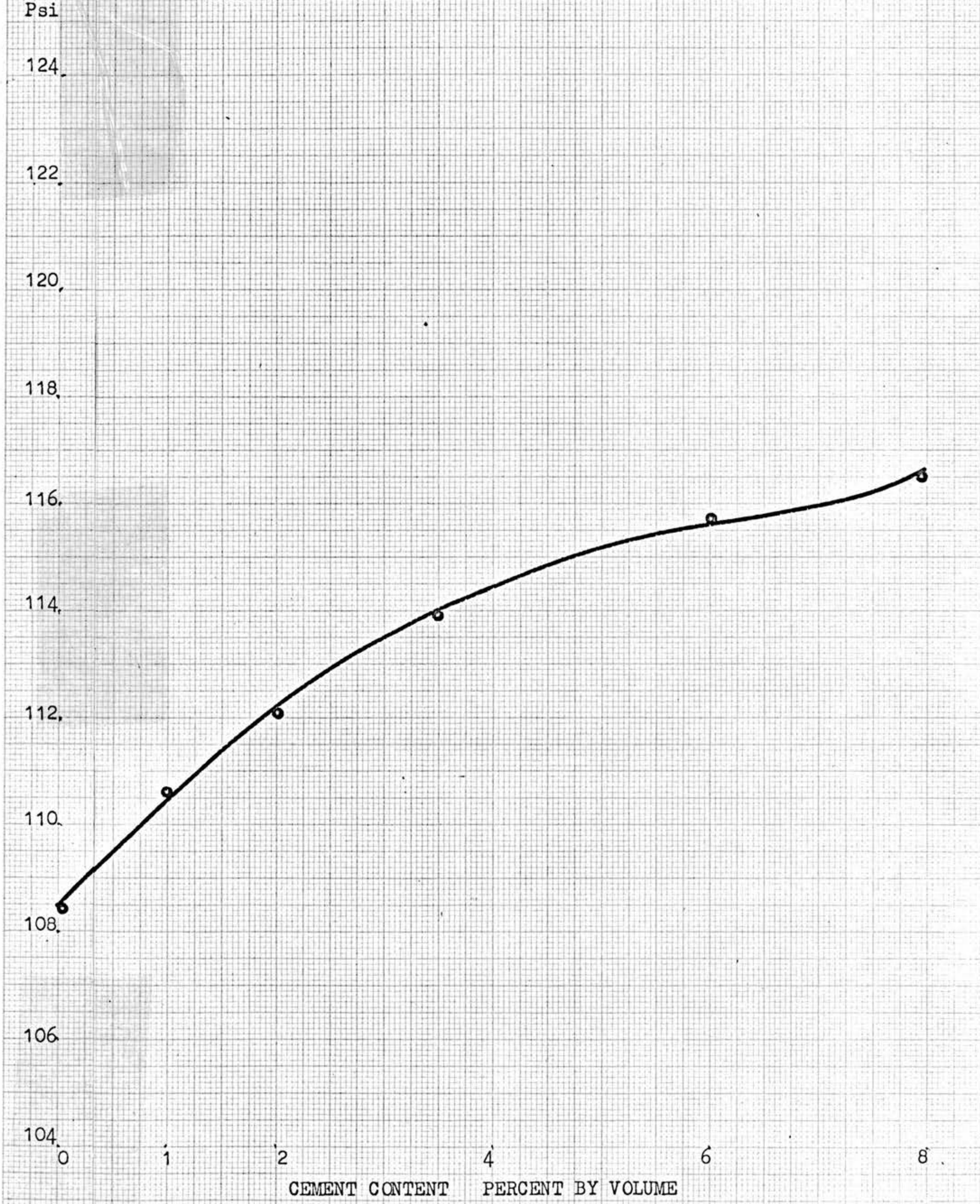
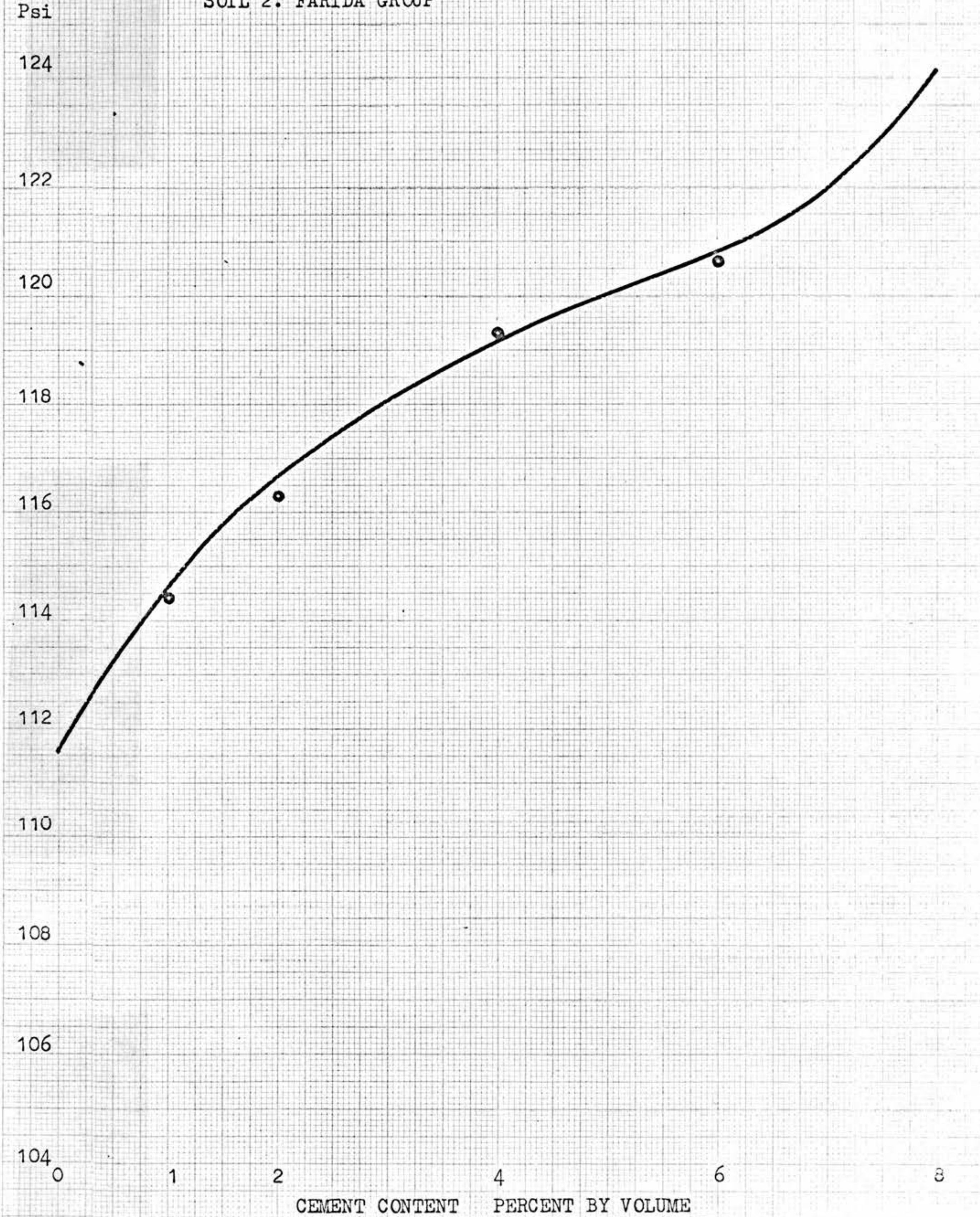


FIG. 11 EFFECT OF CEMENT CONTENT ON DRY DENSITY

SOIL 2. FARIDA GROUP



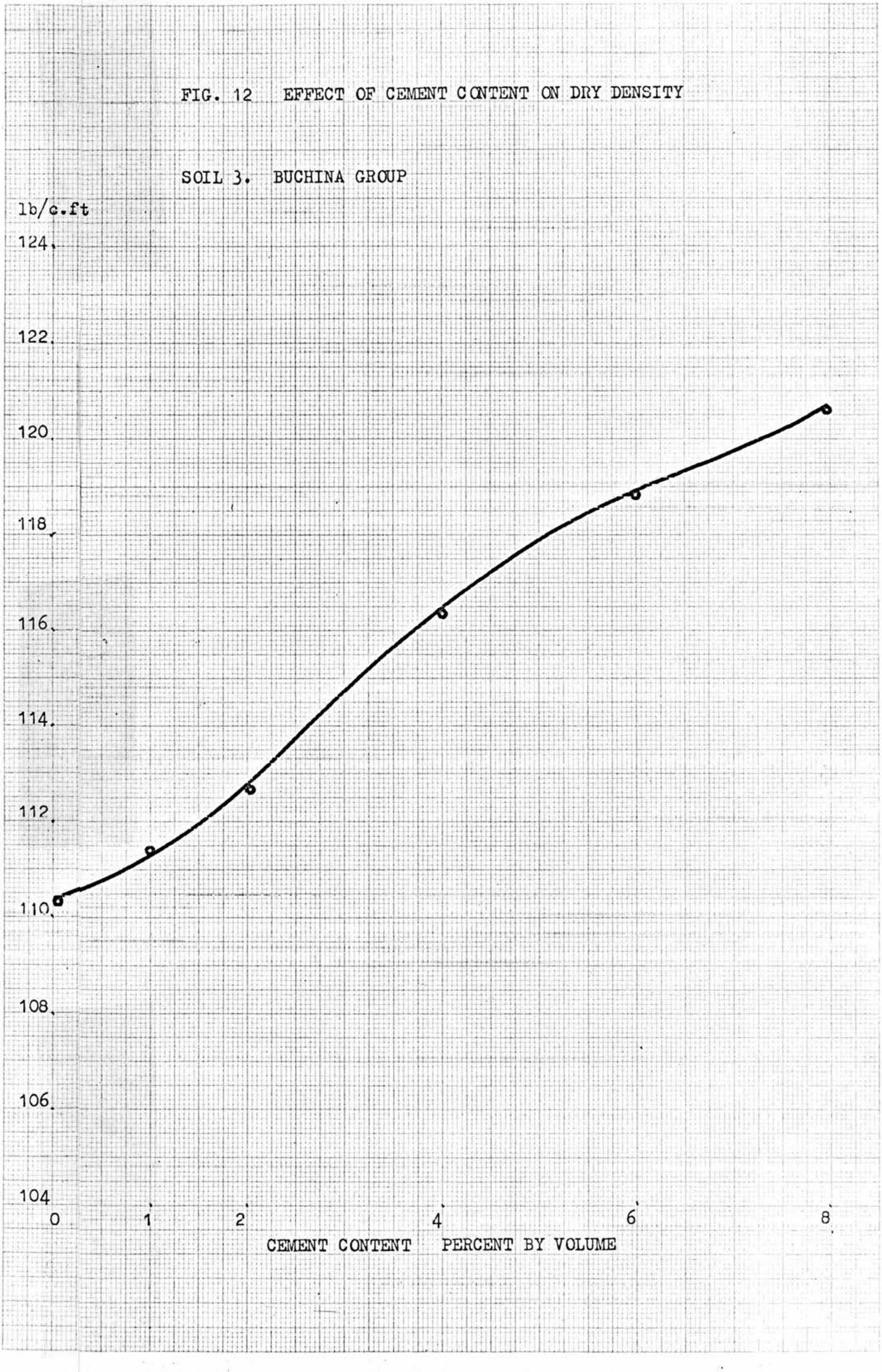


FIG. 12 EFFECT OF CEMENT CONTENT ON DRY DENSITY
SOIL 3. BUCHINA GROUP
lb/c.ft
124
122
120
118
116
114
112
110
108
106
104
0
1
2
4
6
8
CEMENT CONTENT PERCENT BY VOLUME

FIG. 13 EFFECT OF CEMENT CONTENT ON DRY DENSITY

SOIL 4. CHURKANA GROUP

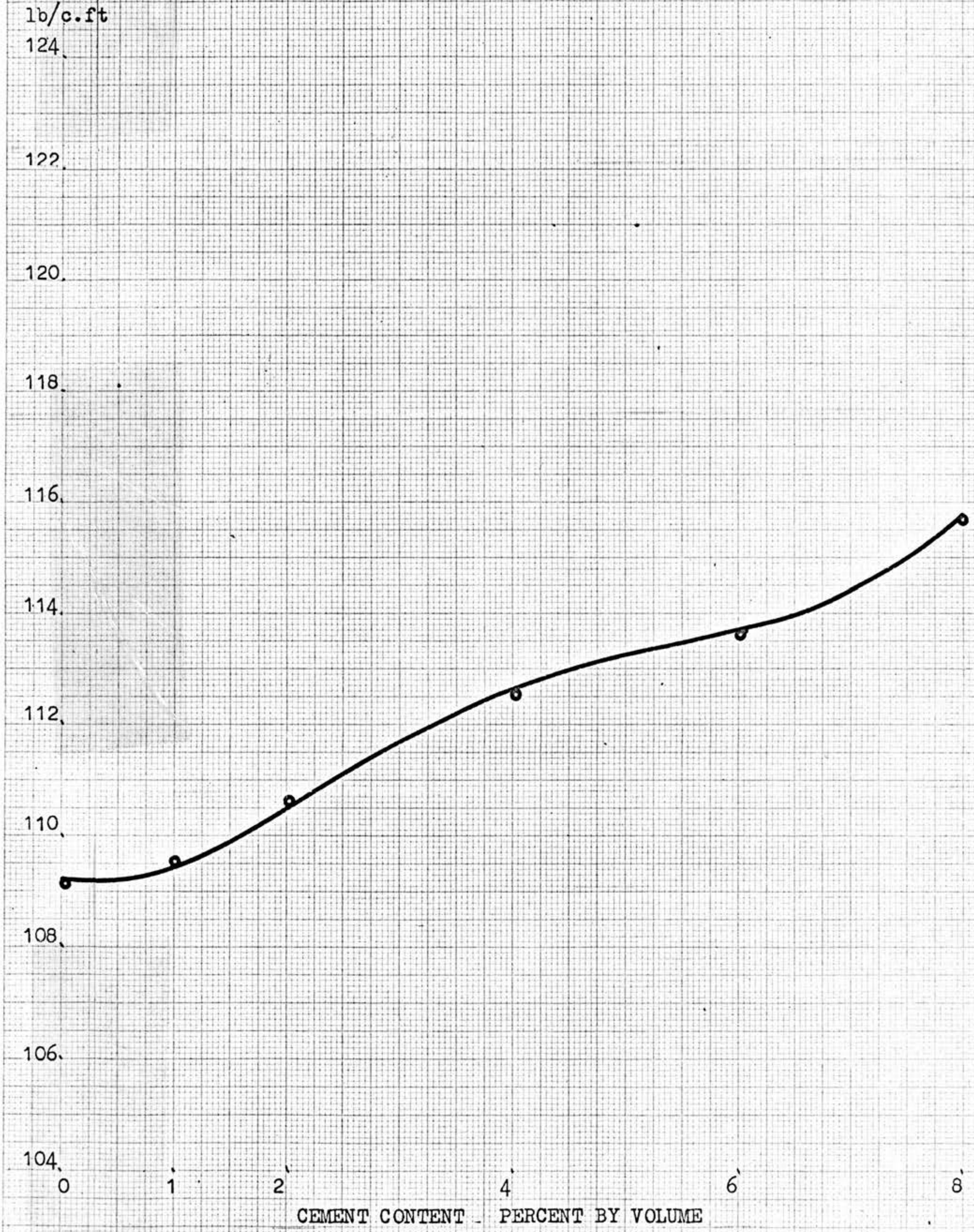


FIG. 14 EFFECT OF CEMENT CONTENT ON DRY DENSITY

SOIL 5. NOKHAR GROUP

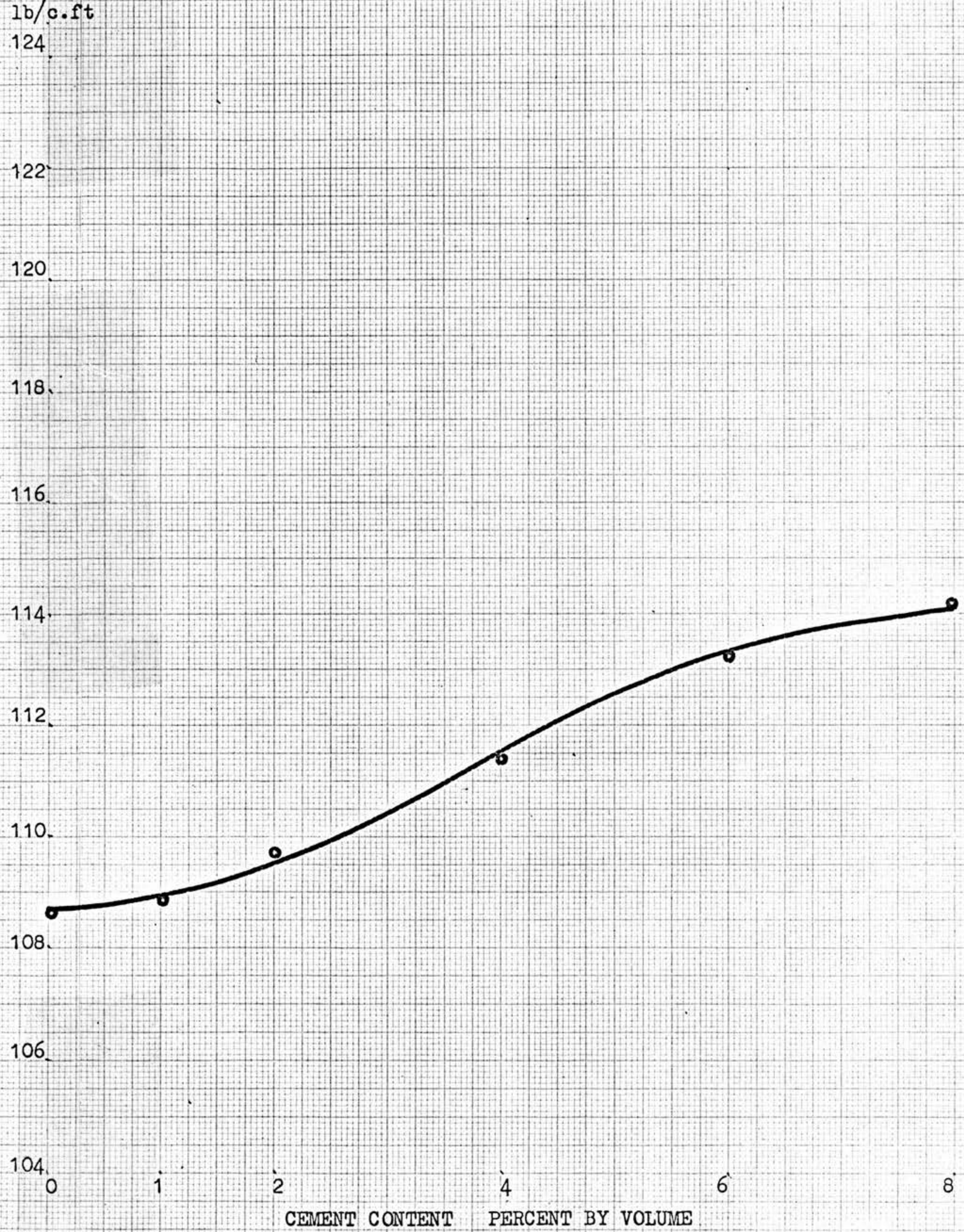


FIG. 15 EFFECT OF CEMENT CONTENT ON COMPRESSIVE STRENGTH

SOIL 1. JHANG GROUP

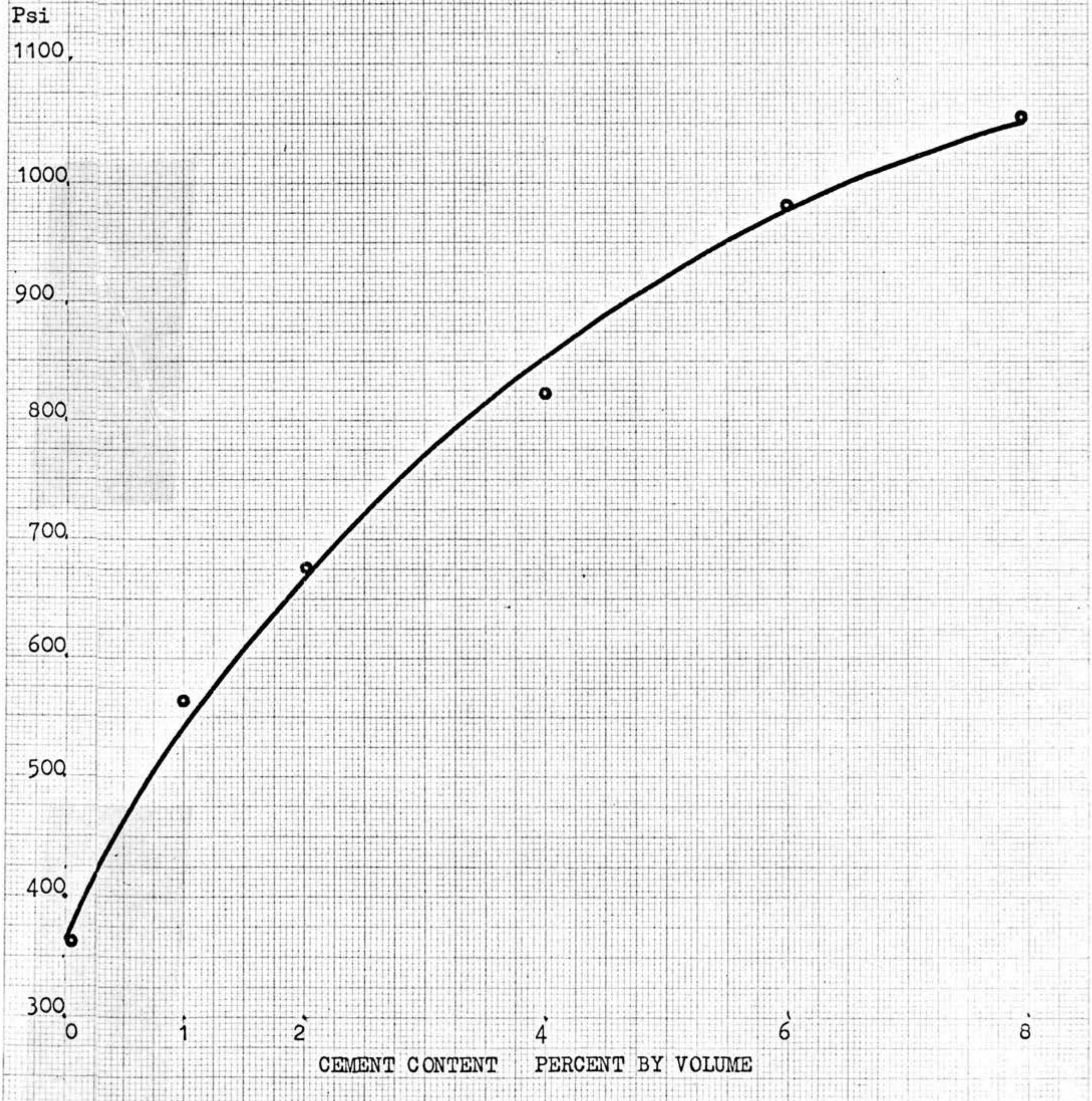


FIG. 16 EFFECT OF CEMENT CONTENT ON COMPRESSIVE STRENGTH

SOIL 2. FARIDA GROUP

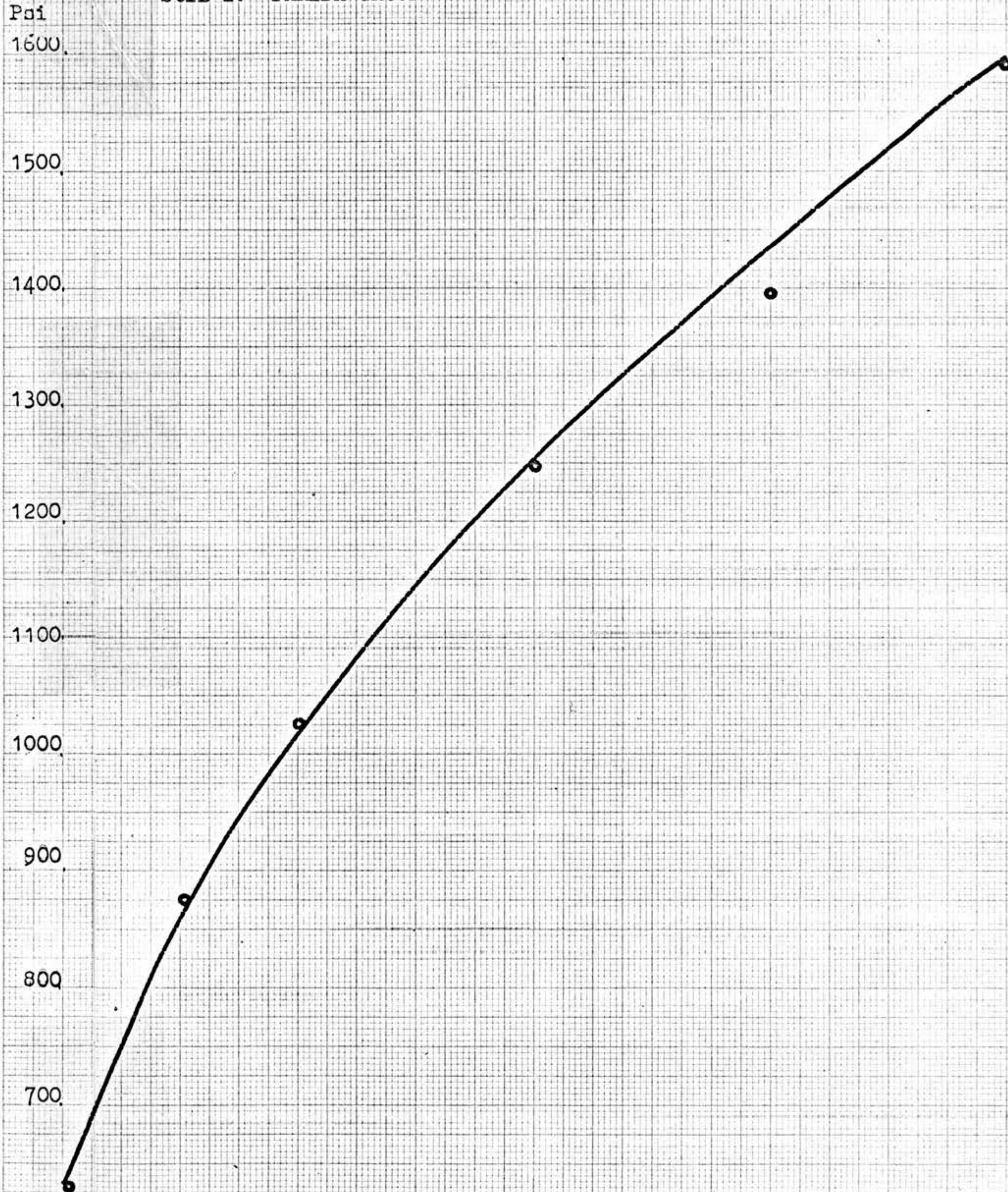


FIG. 17 EFFECT OF CEMENT CONTENT ON COMPRESSIVE STRENGTH

SOIL 3. BUCHINA GROUP

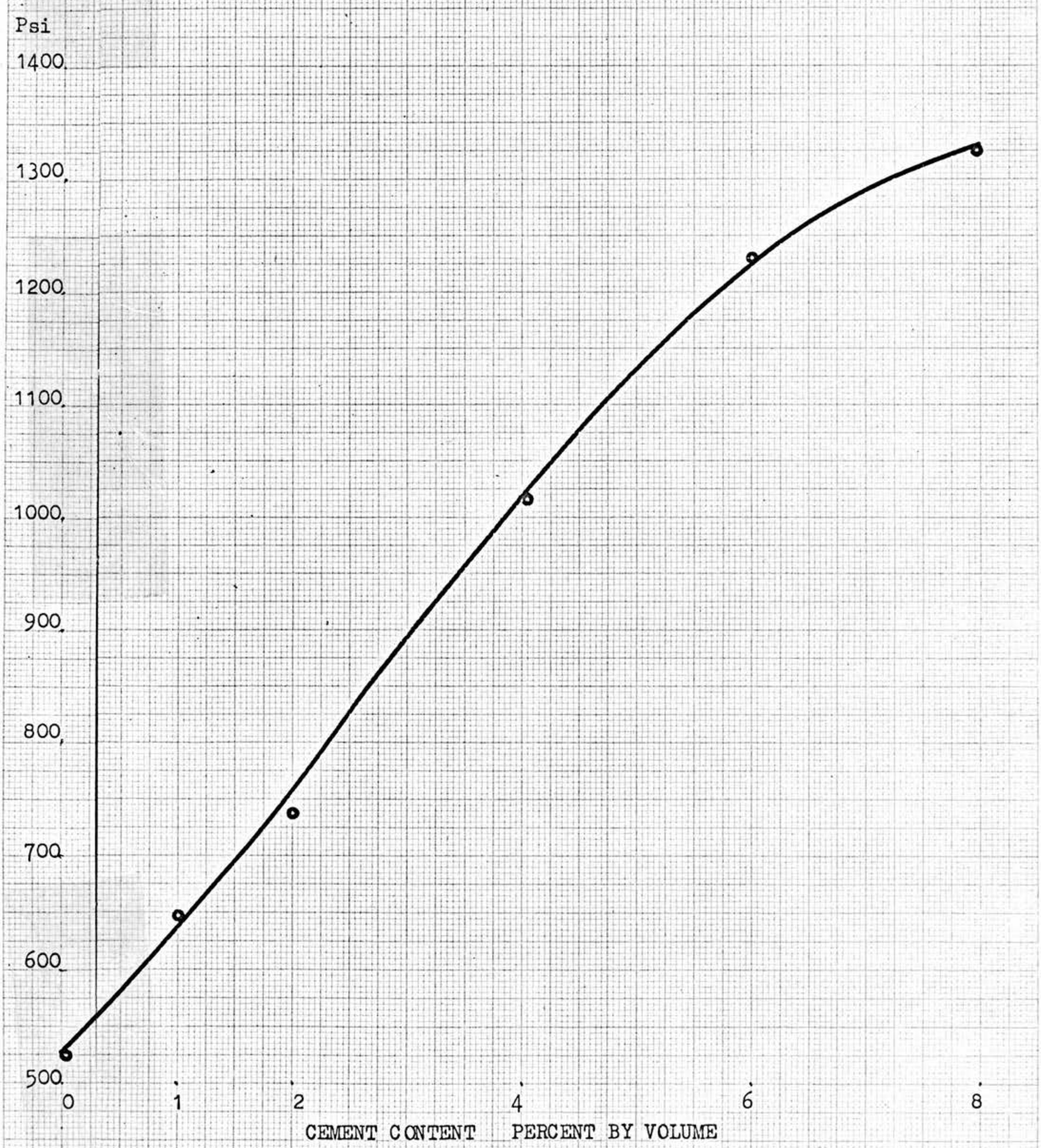


FIG. 18 EFFECT OF CEMENT CONTENT ON COMPRESSIVE STRENGTH

SOIL 4. CHURKANA GROUP

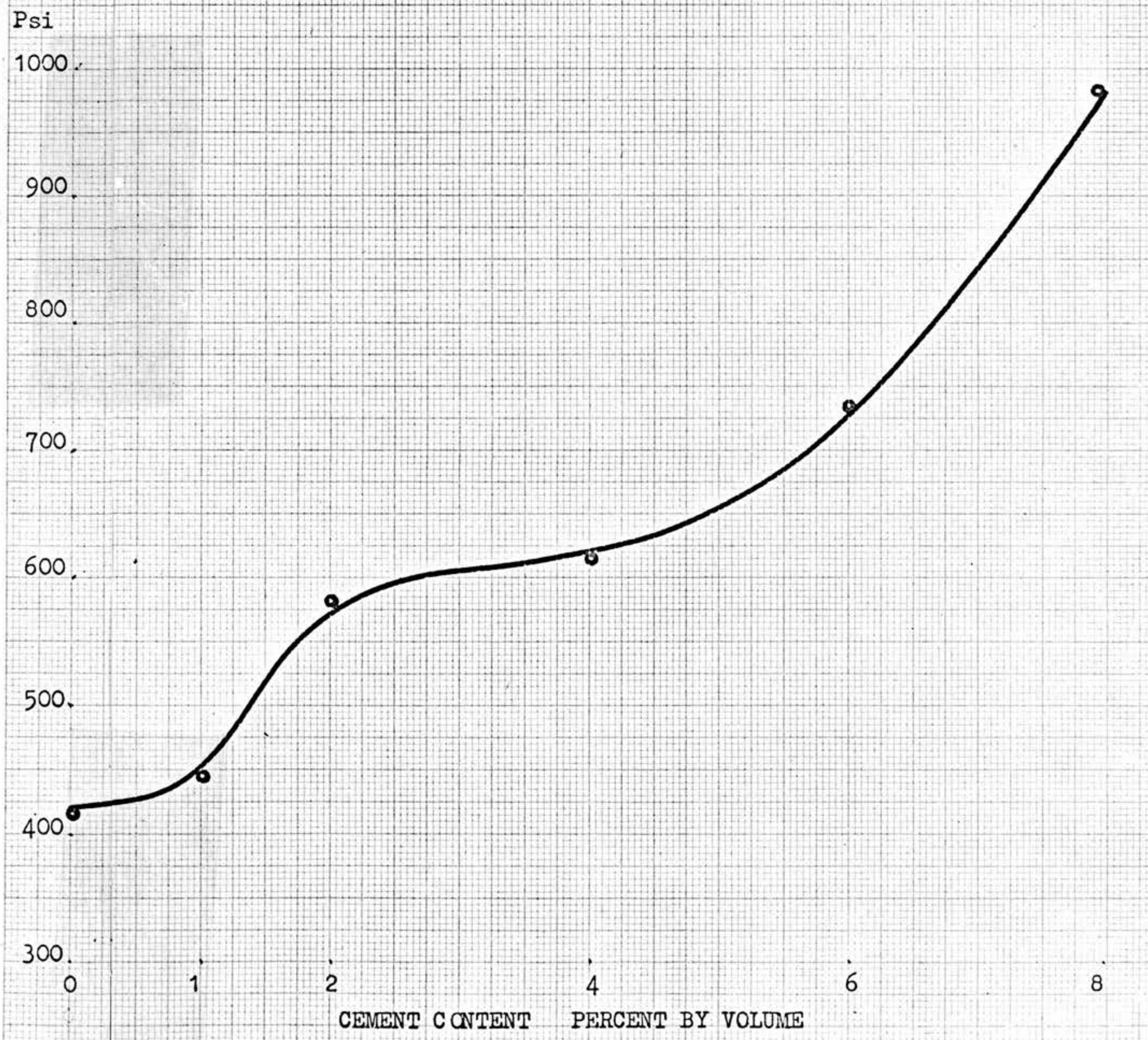


FIG. 19 EFFECT OF CEMENT CONTENT ON COMPRESSIVE STRENGTH

SOIL 5. NOKHAR GROUP

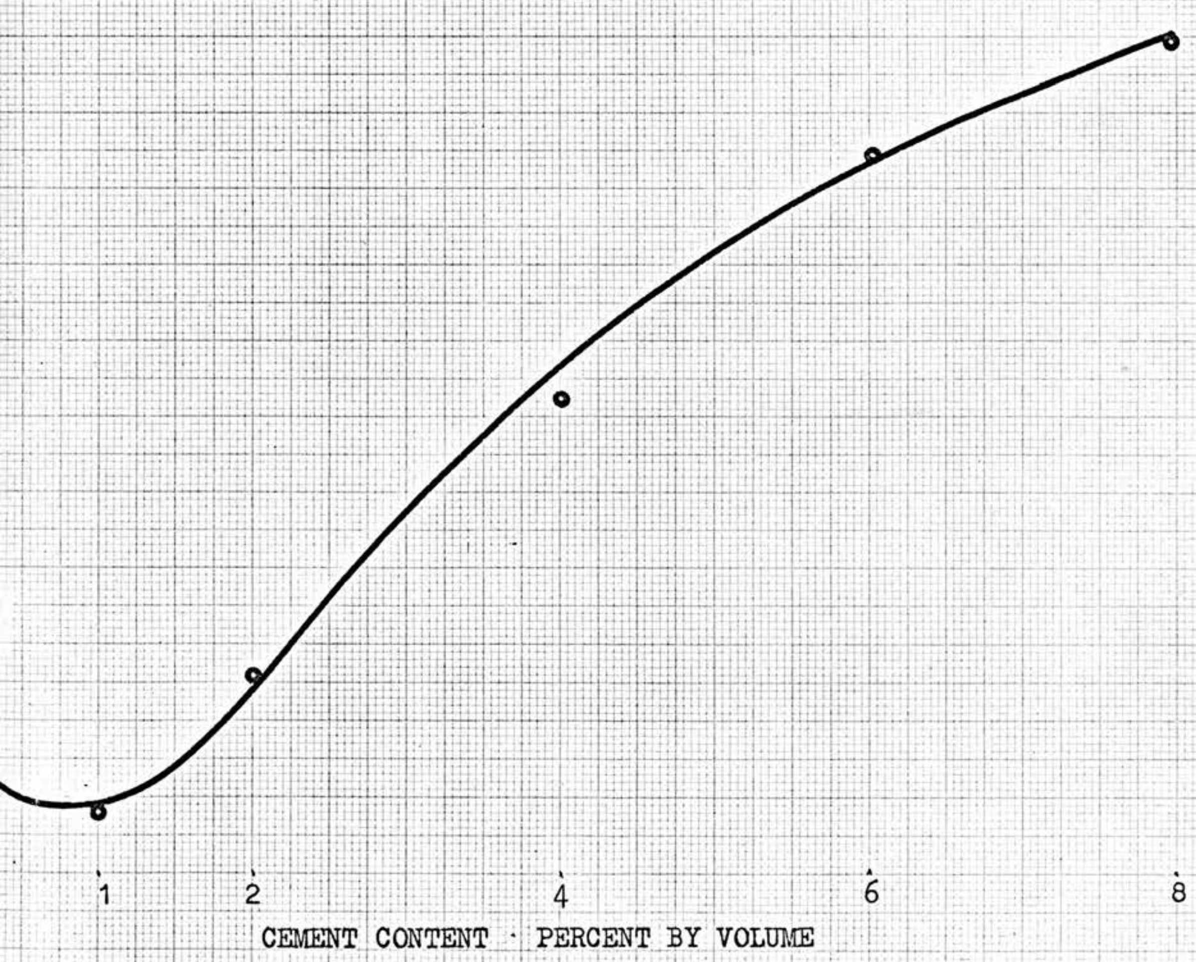


FIG. 20 EFFECT OF CEMENT CONTENT ON VOLUMETRIC SHRINKAGE

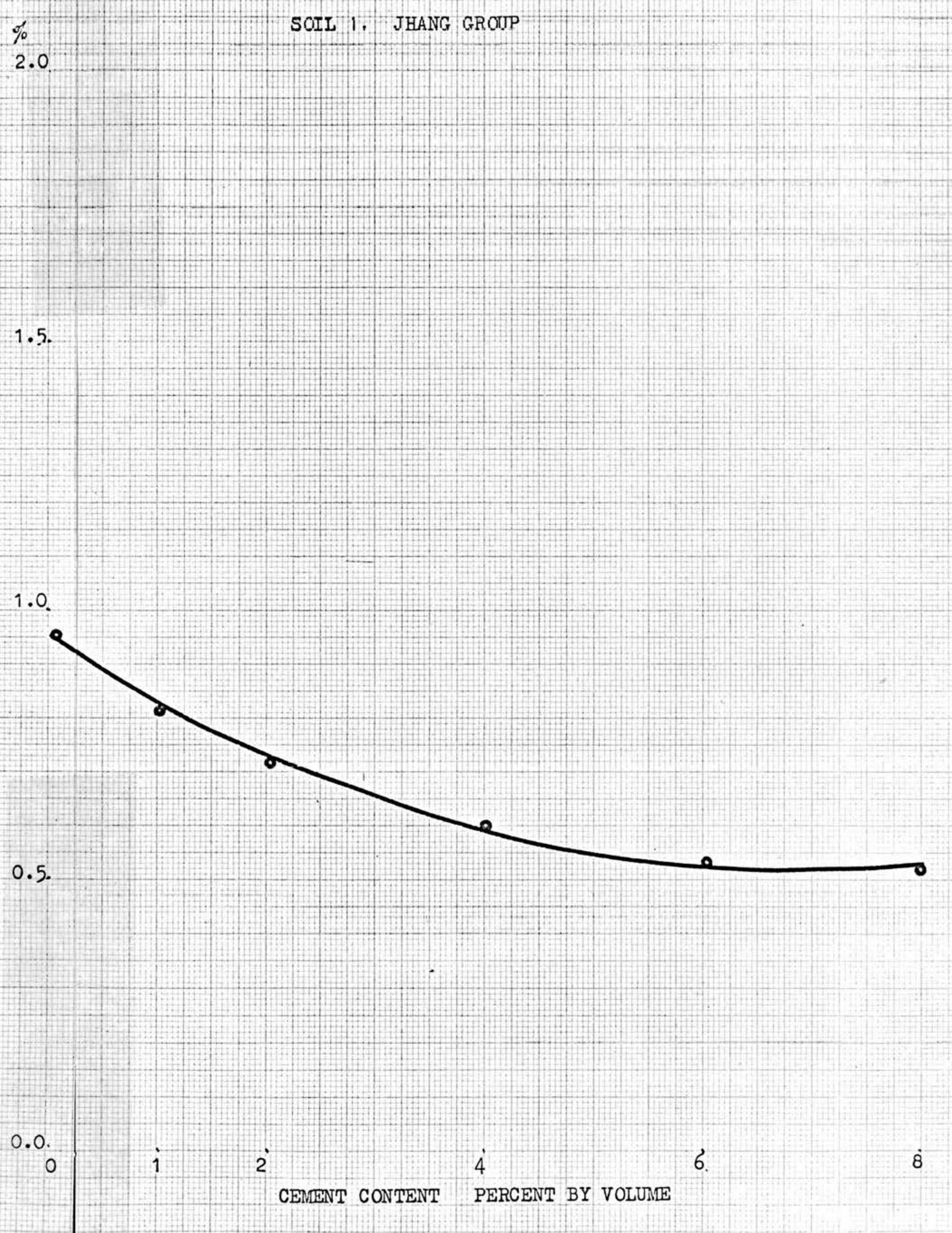


FIG. 21 EFFECT OF CEMENT CONTENT
VOLUMETRIC SHRINKAGE

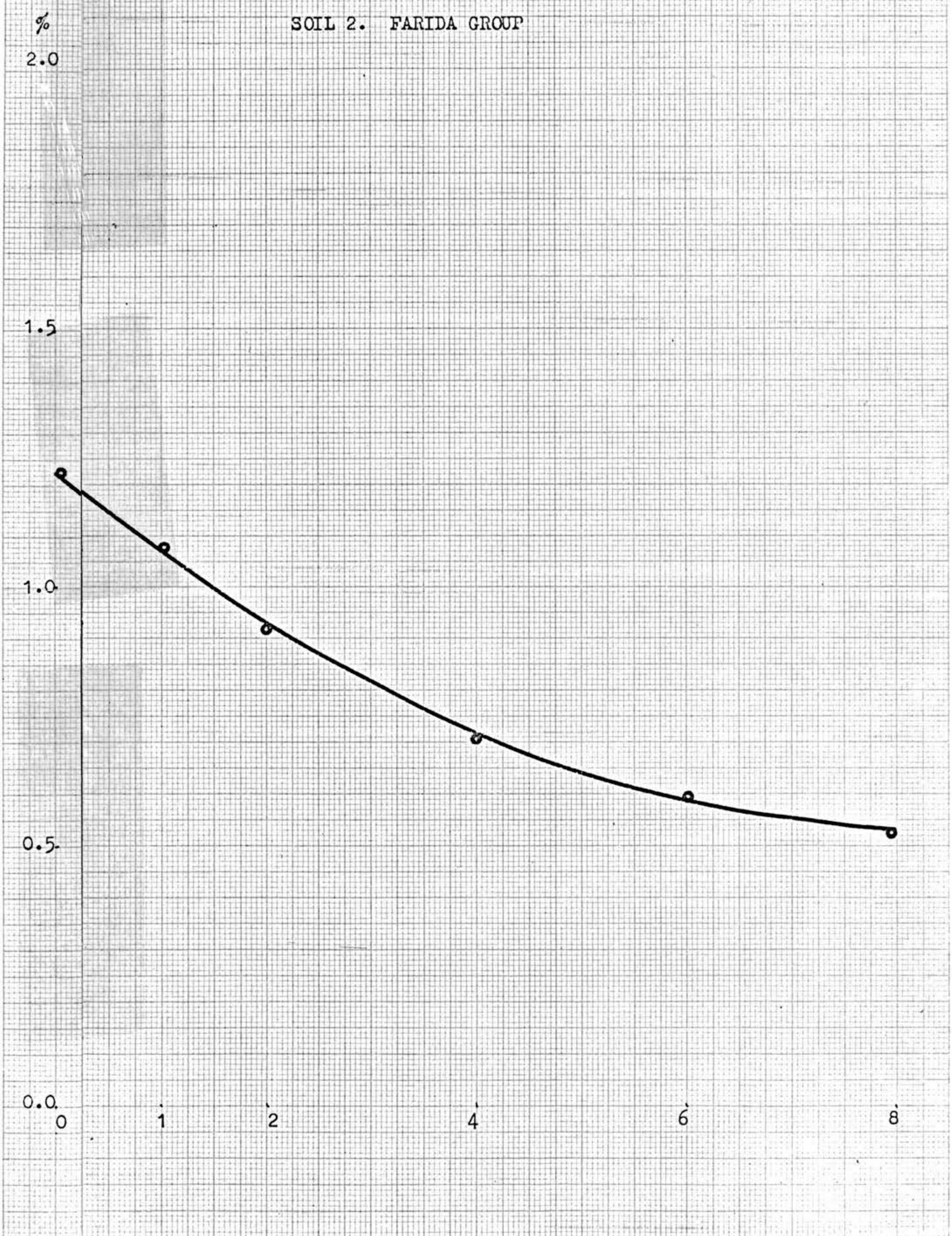
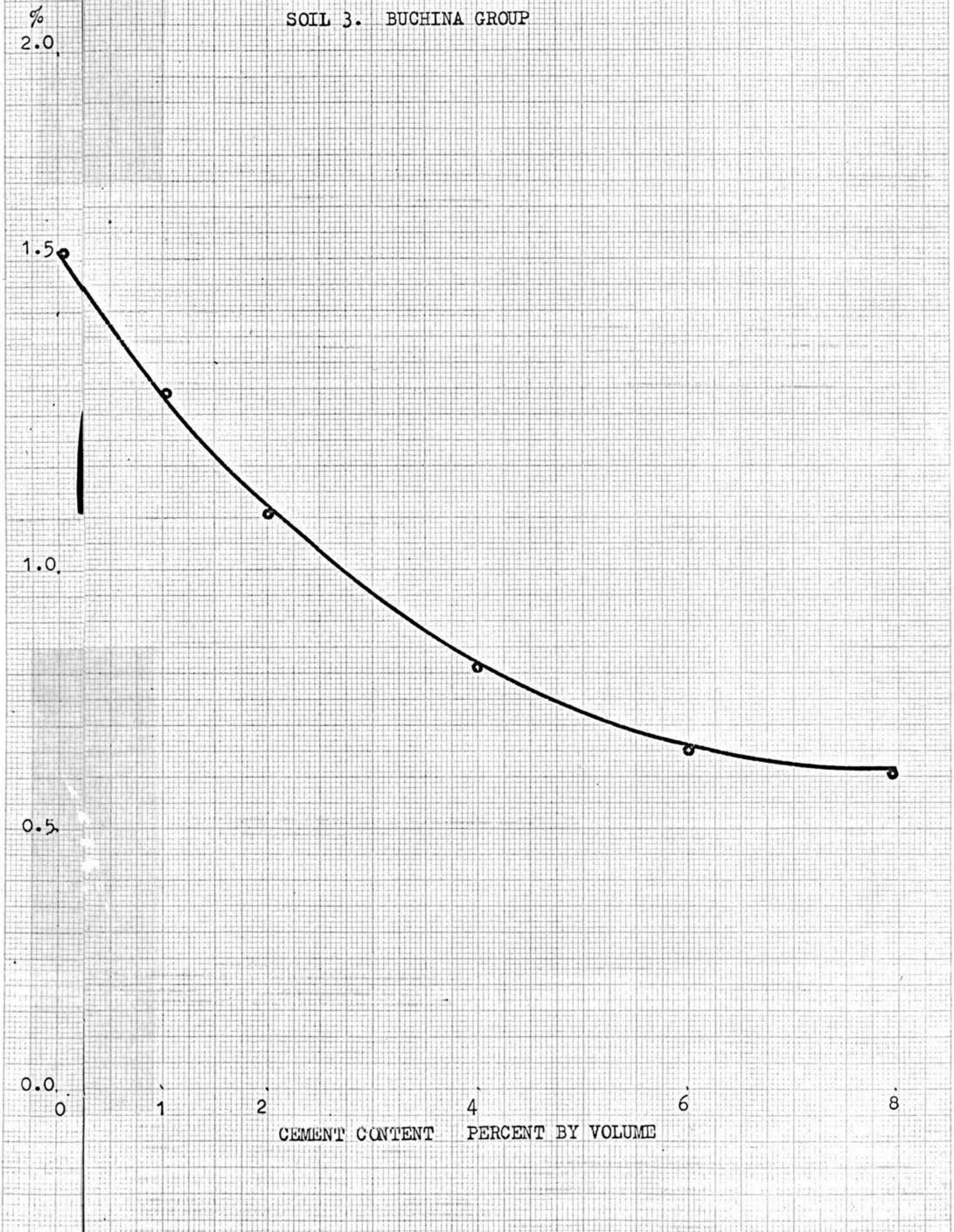


FIG. 22 EFFECT OF CEMENT CONTENT
ON VOLUMETRIC SHRINKAGE

SOIL 3. BUCHINA GROUP



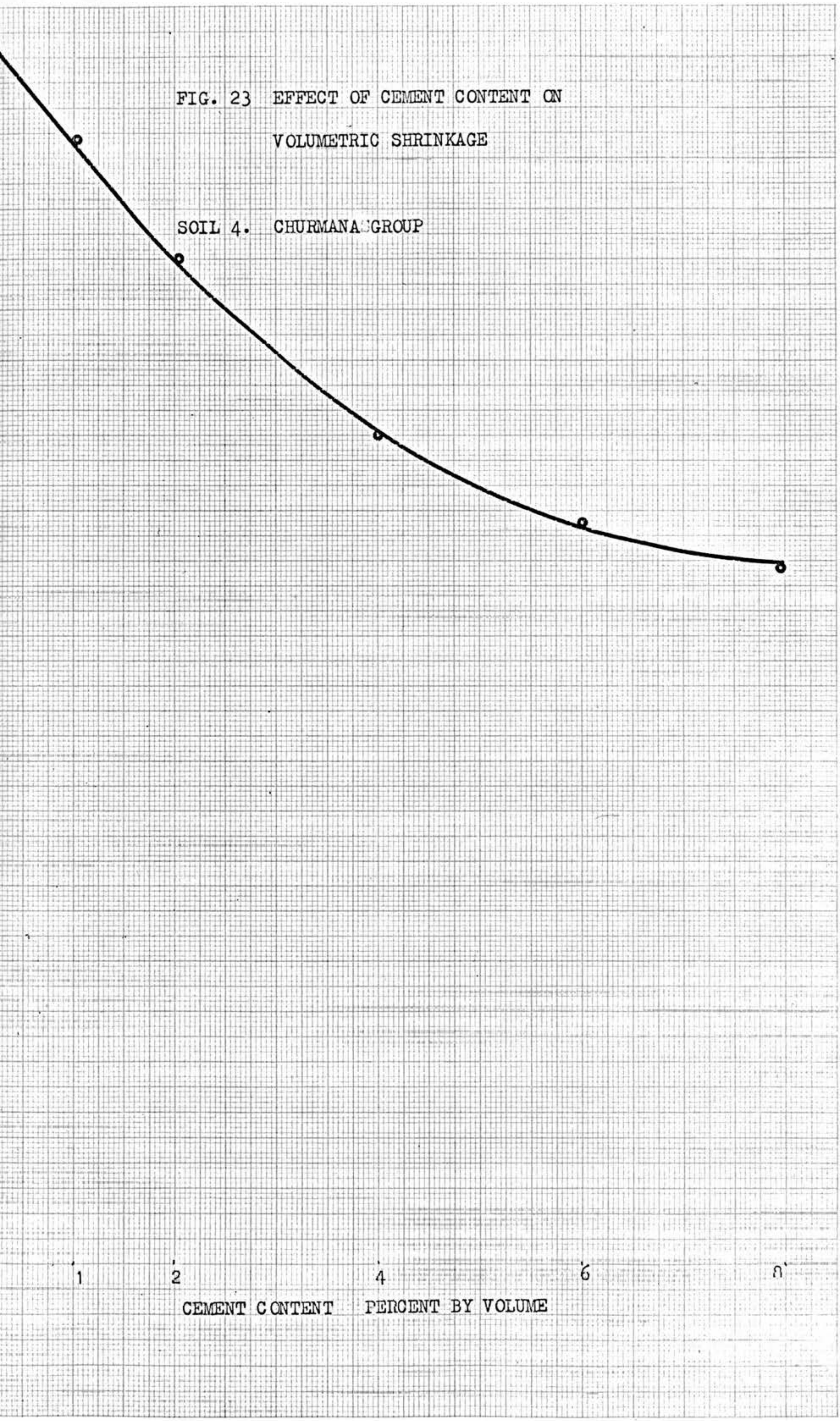


FIG. 23 EFFECT OF CEMENT CONTENT ON VOLUMETRIC SHRINKAGE

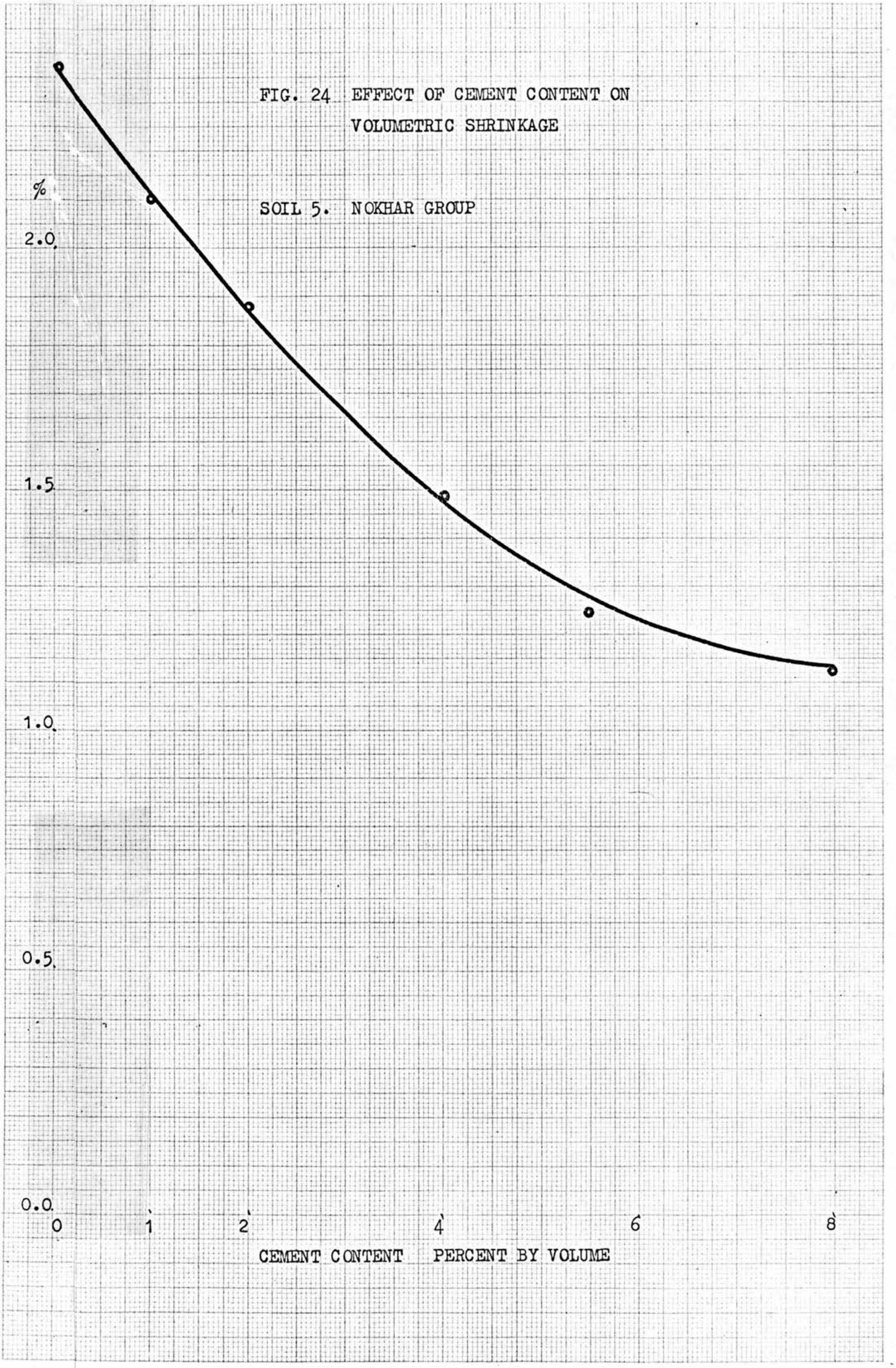


FIG. 24 EFFECT OF CEMENT CONTENT ON VOLUMETRIC SHRINKAGE

FIG. 25 EFFECT OF CEMENT CONTENT ON
WEIGHT LOSS

SOIL 1. JHANG GROUP

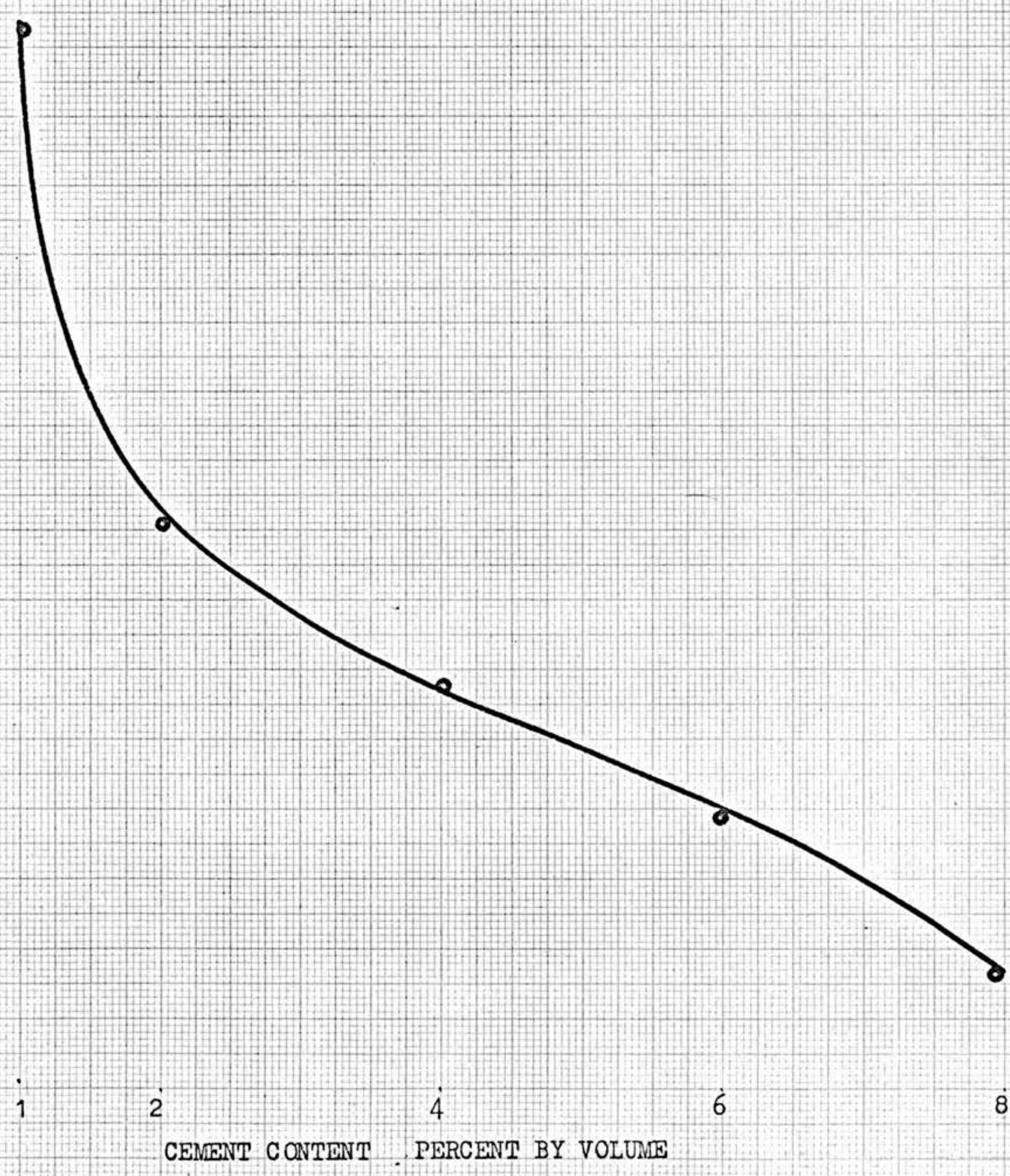
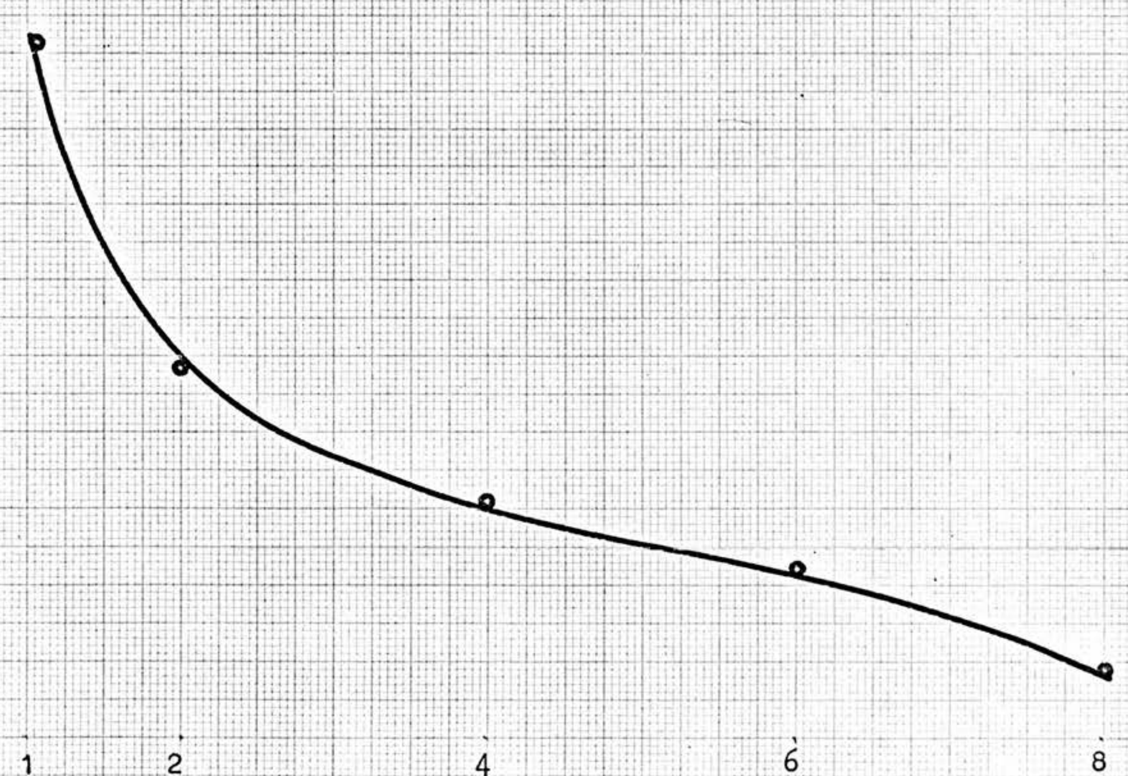


FIG. 26 EFFECT OF CEMENT CONTENT ON WEIGHT LOSS

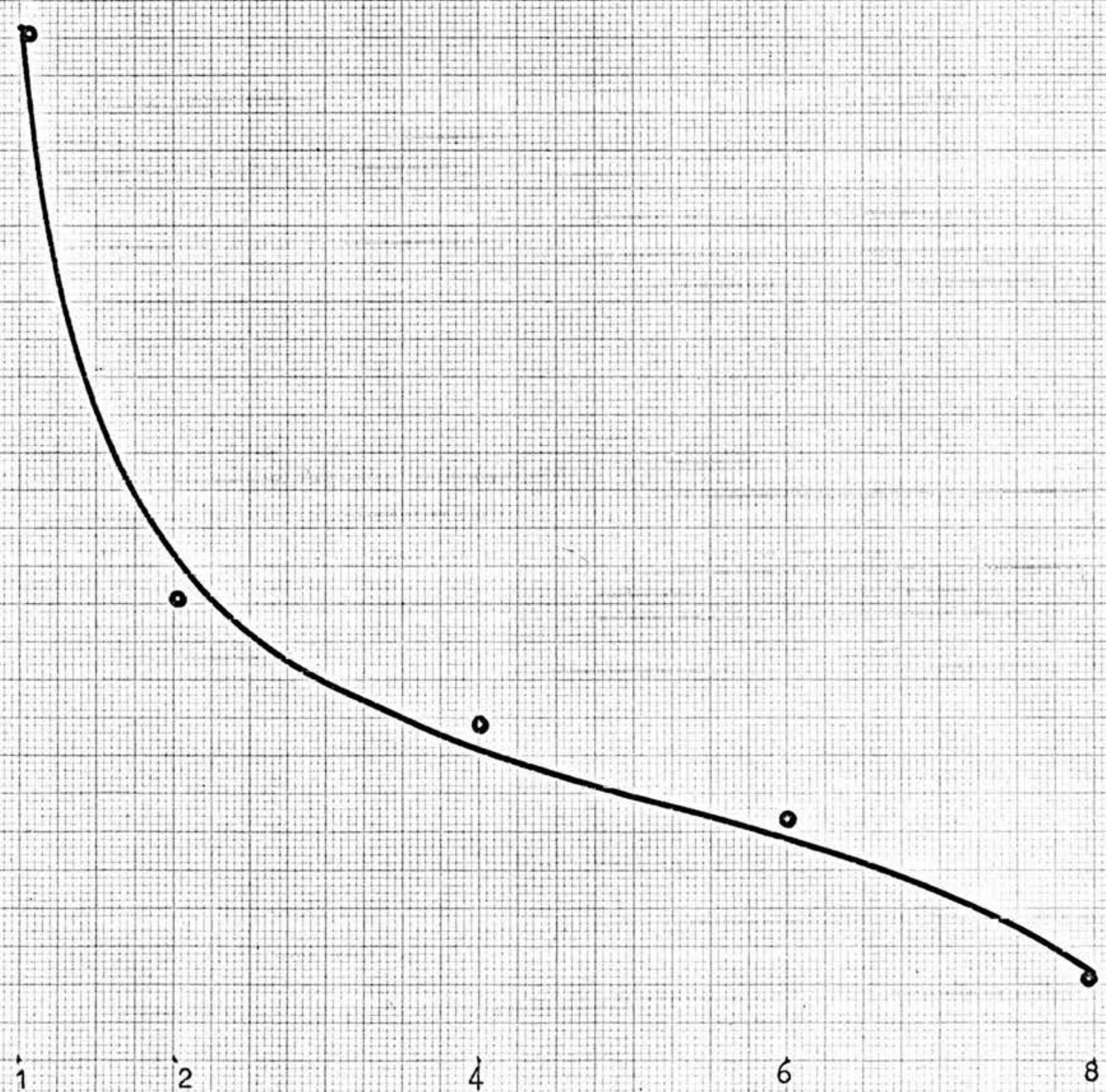
SOIL 2. FARIDA GROUP



CEMENT CONTENT PERCENT BY VOLUME

FIG. 27 EFFECT OF CEMENT CONTENT ON WEIGHT LOSS

SOIL 3. BUCHINA GROUP



CEMENT CONTENT PERCENT BY VOLUME

FIG. 28 EFFECT OF CEMENT CONTENT ON WEIGHT LOSS

SOIL 4. CHURKANA GROUP

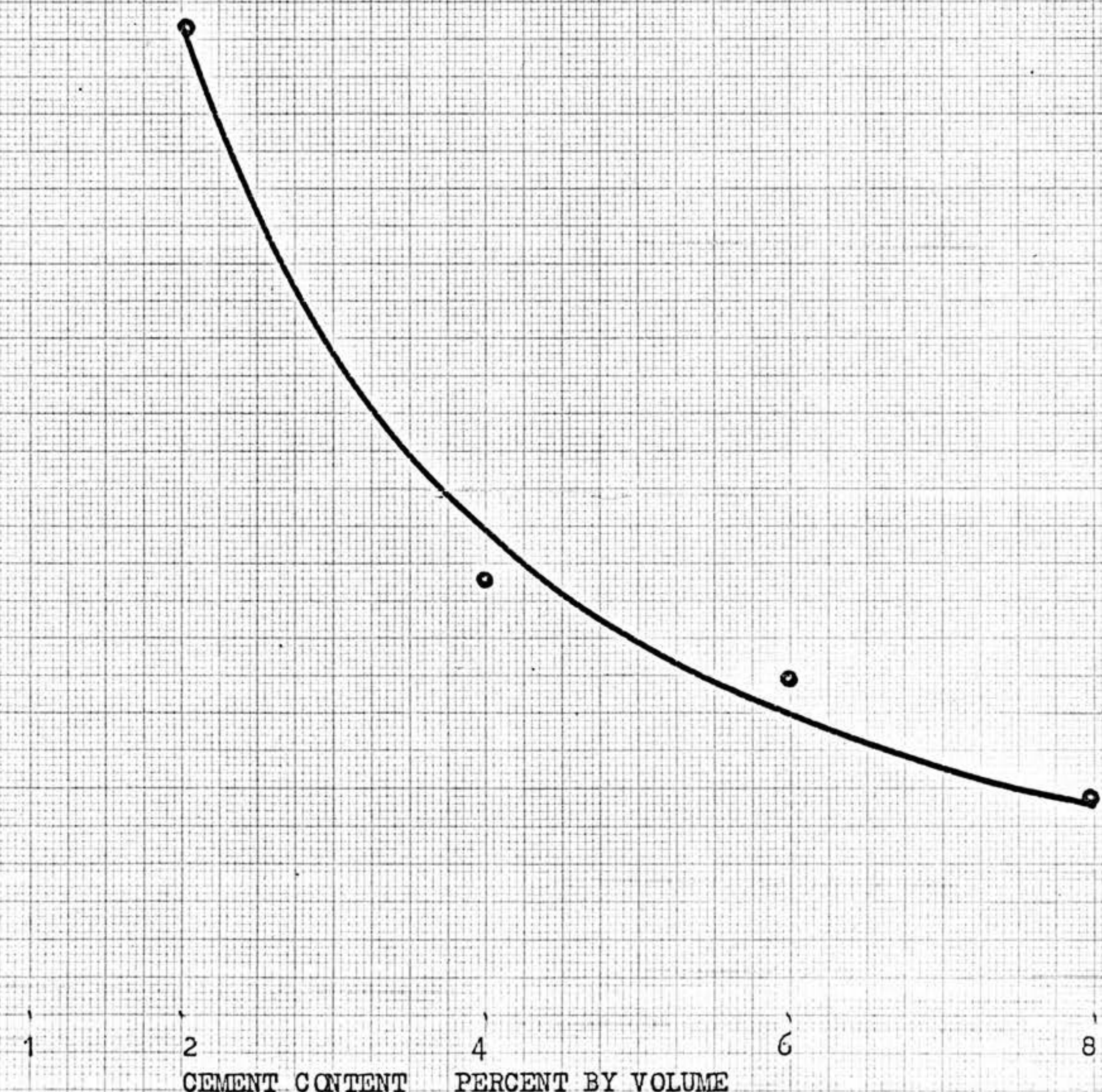
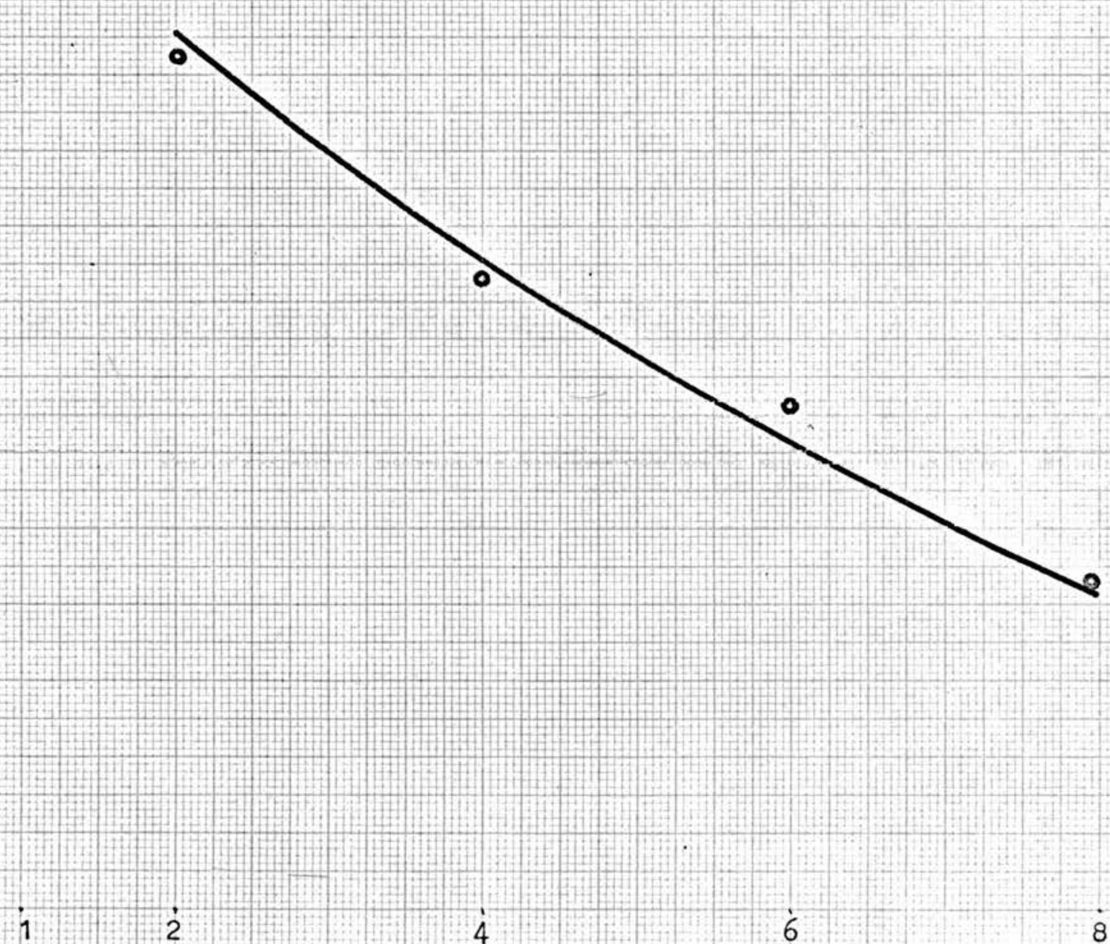


FIG. 29 EFFECT OF CEMENT CONTENT ON WEIGHT LOSS

SOIL 5. NOKHAR GROUP



CEMENT CONTENT PERCENT BY VOLUME

CHAPTER 8

THE WATER REQUIREMENTS

The water requirements of soil can be determined from density measurements alone. It was not considered within the scope of this project to investigate other influences of the varying moisture contents (e.g. on Volumetric Shrinkage and Weight Loss) because optimum moisture of compaction for each group would, at any rate, be the one at which maximum density is obtained.[1]

8.1 WATER IN STABILIZATION

The significance of water in soil stabilization is mainly due to its influence on compaction.[2] At moisture contents below the optimum the soil particles are locked in an open texture, the soil is therefore stiff and difficult to compress; thus low dry densities and high air contents are obtained. As the moisture content increases, the water acts as lubricant, allowing the fines to be forced into the voids between the larger particles, under the influence of external compactive energy. Different soils and different mixes together with the degree of fineness of the different particles require different proportions of water in order to obtain good compaction. It has been shown that for each soil there is an optimum moisture content at which a given amount of mechanical effort will produce maximum compaction. At moisture contents above the optimum the soil is displaced sideways and energy is not wholly used for compaction.[3] Within limits the greater the

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1. Density is recognised as the measure of the degree of compaction.
2. Other influences of water have been discussed in Chapter 3.
3. This point is discussed in detail in Chapter 9.

compactive force the lower is the optimum moisture content and the greater is the degree of compaction obtained.[1]

Another role of moisture in stabilization is its use for the hydration of cement but at the optimum moisture content the amount of water present in the mixture adequately meets this requirement.[2]

8.2 DETERMINING THE WATER REQUIREMENTS

The optimum moisture content of each soil without any addition of cement was determined according to standard method which involved plotting the dry densities obtained in a series of determinations against the corresponding moisture contents. The position of maximum on a smooth curve drawn through the resulting points gave the optimum moisture of compaction.[3]

8.2.1 Dry Density

As noted above for all soils the maximum dry densities were obtained at their respective optimum moisture contents. An increase or decrease over this moisture produced marked decrease in the dry densities obtained. Optimum moisture content for clay soils was higher than those for sandy soils. (See Figs.30-34).

8.2.2 Compressive Strength

The compressive strength of any specimen was also found to reflect a direct influence of the moisture of compaction. Maximum strengths occurred at or near optimum moisture contents. (See Figs.35-39).

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1. See Fig.40.
2. BUILDING RESEARCH STATION, "Colonial Building Notes", August 1952,p.5.
3. See Fig.6.

FIG.30 . EFFECT OF MOISTURE OF COMPACTION ON
DRY DENSITY

SOIL 1. JIANG GROUT

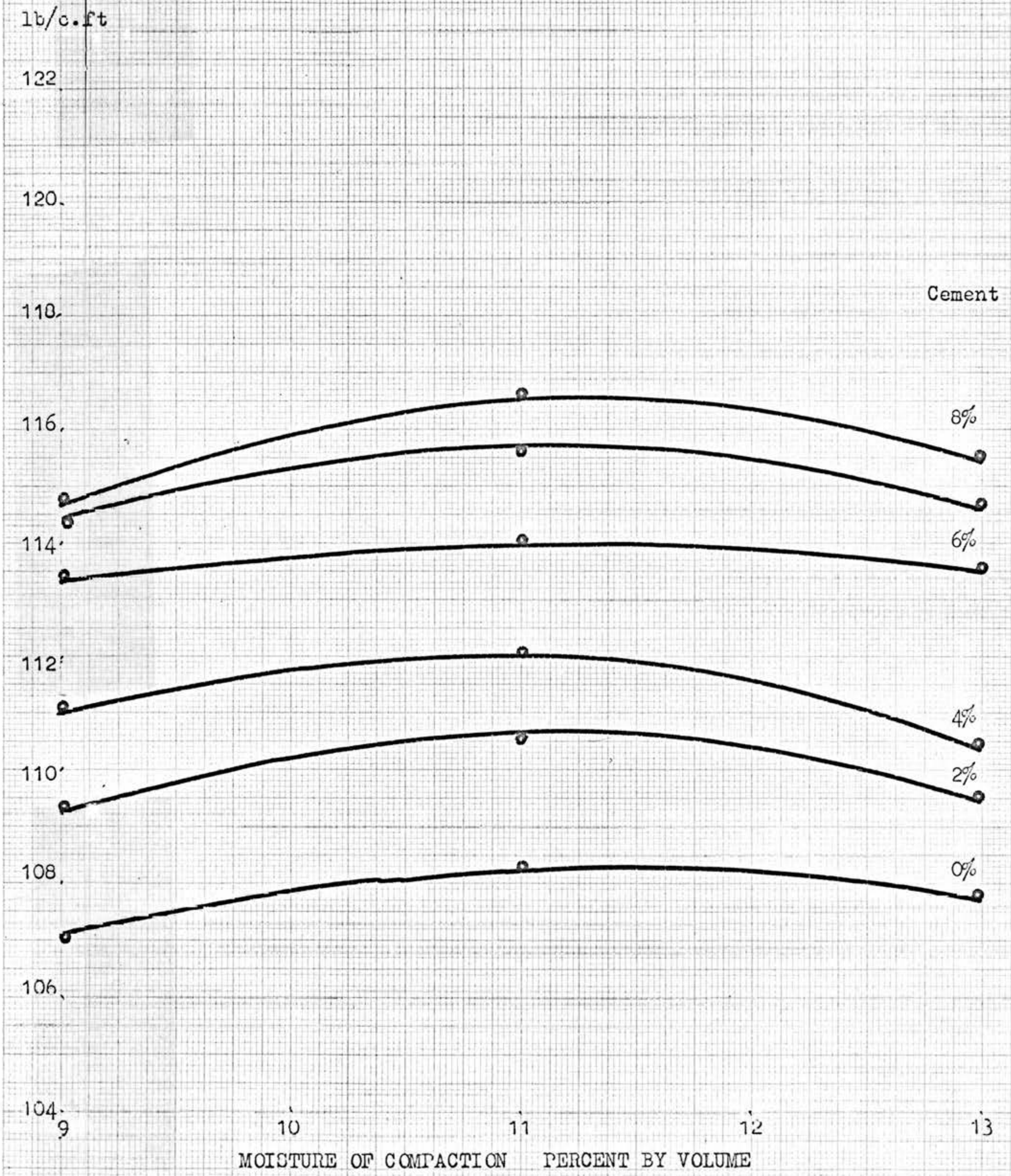


FIG. 31 EFFECT OF MOISTURE OF COMPACTION ON DRY DENSITY

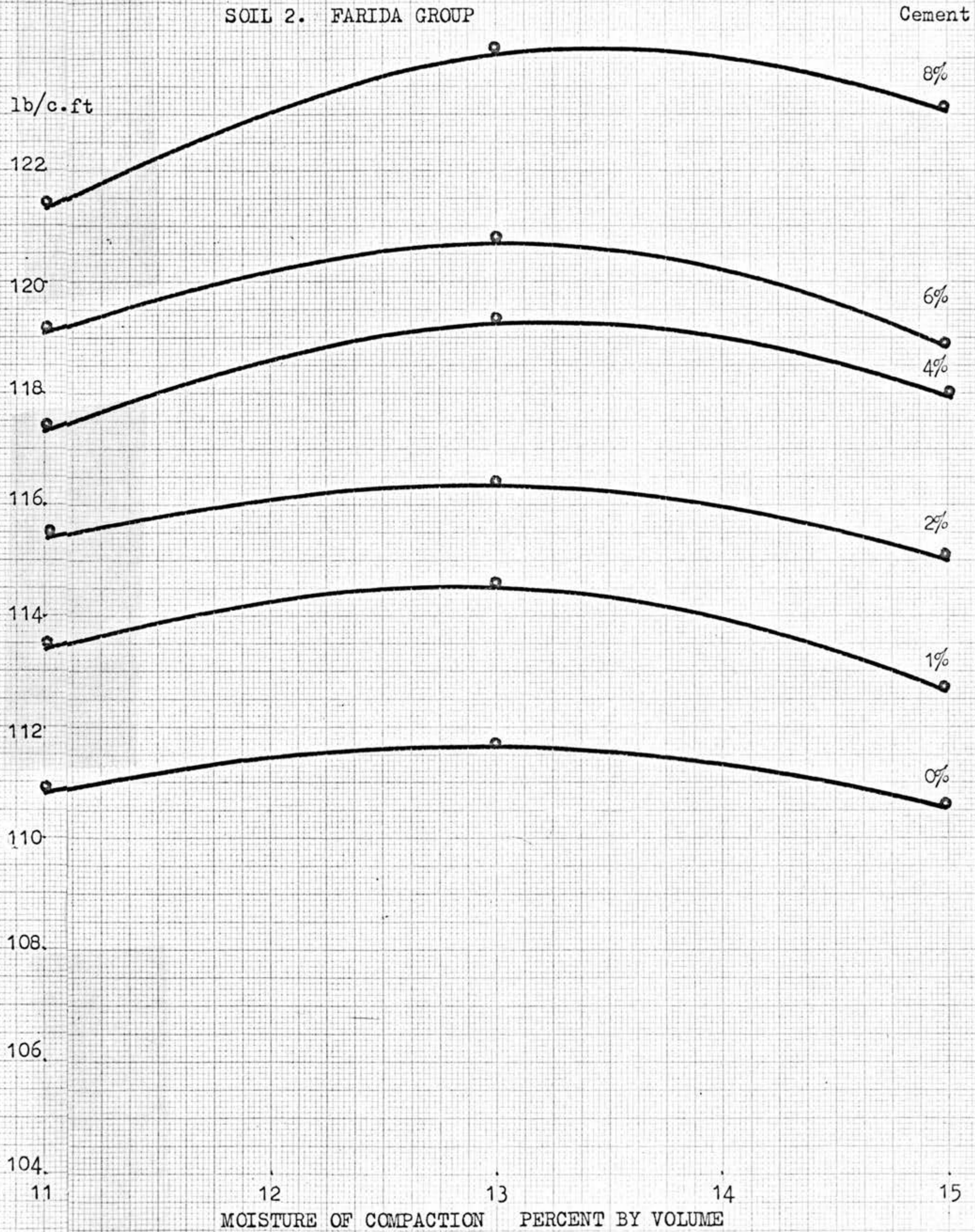


FIG. 32 EFFECT OF MOISTURE OF COMPACTION ON DRY DENSITY

SOIL 3. BUCHINA GROUP

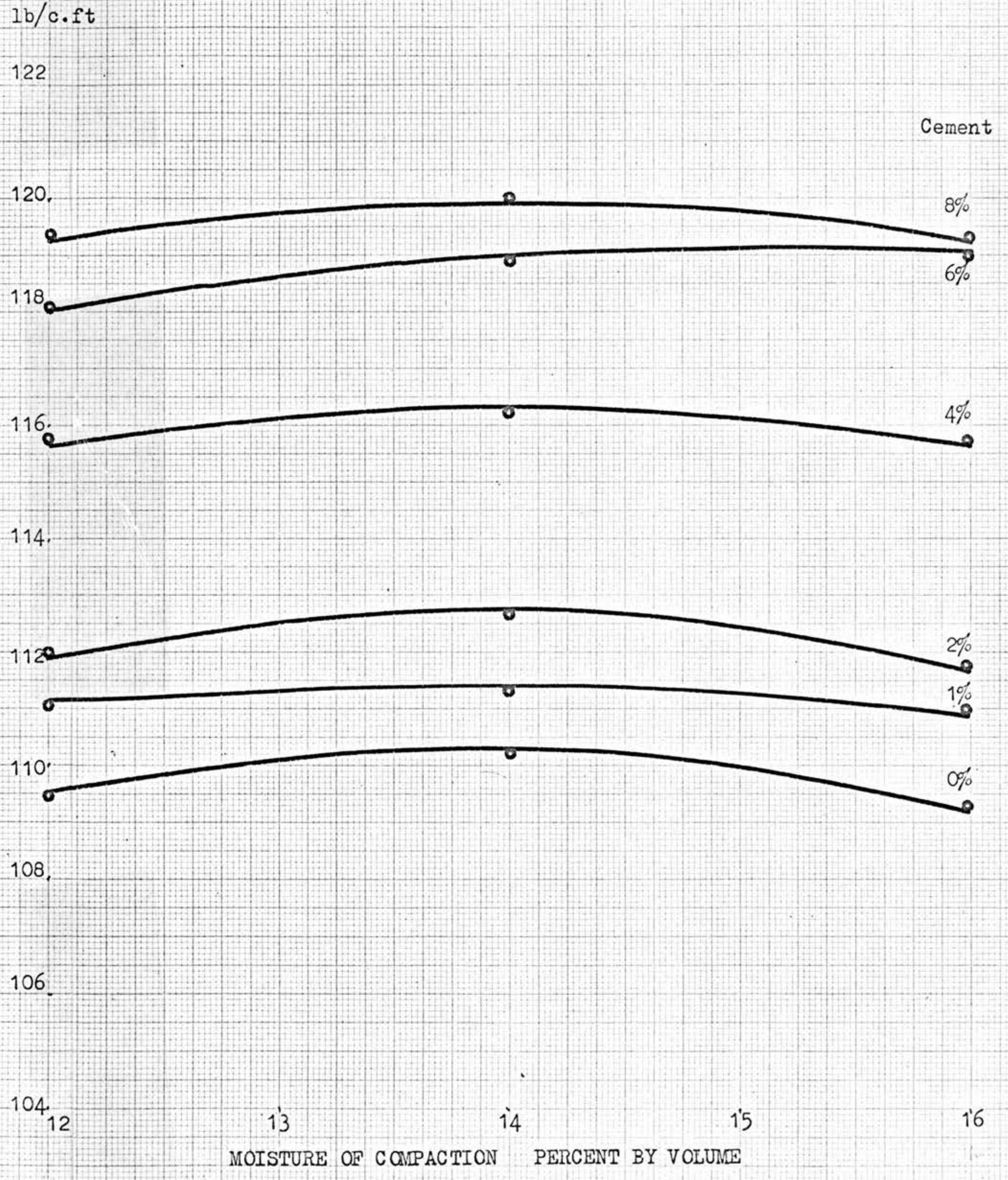
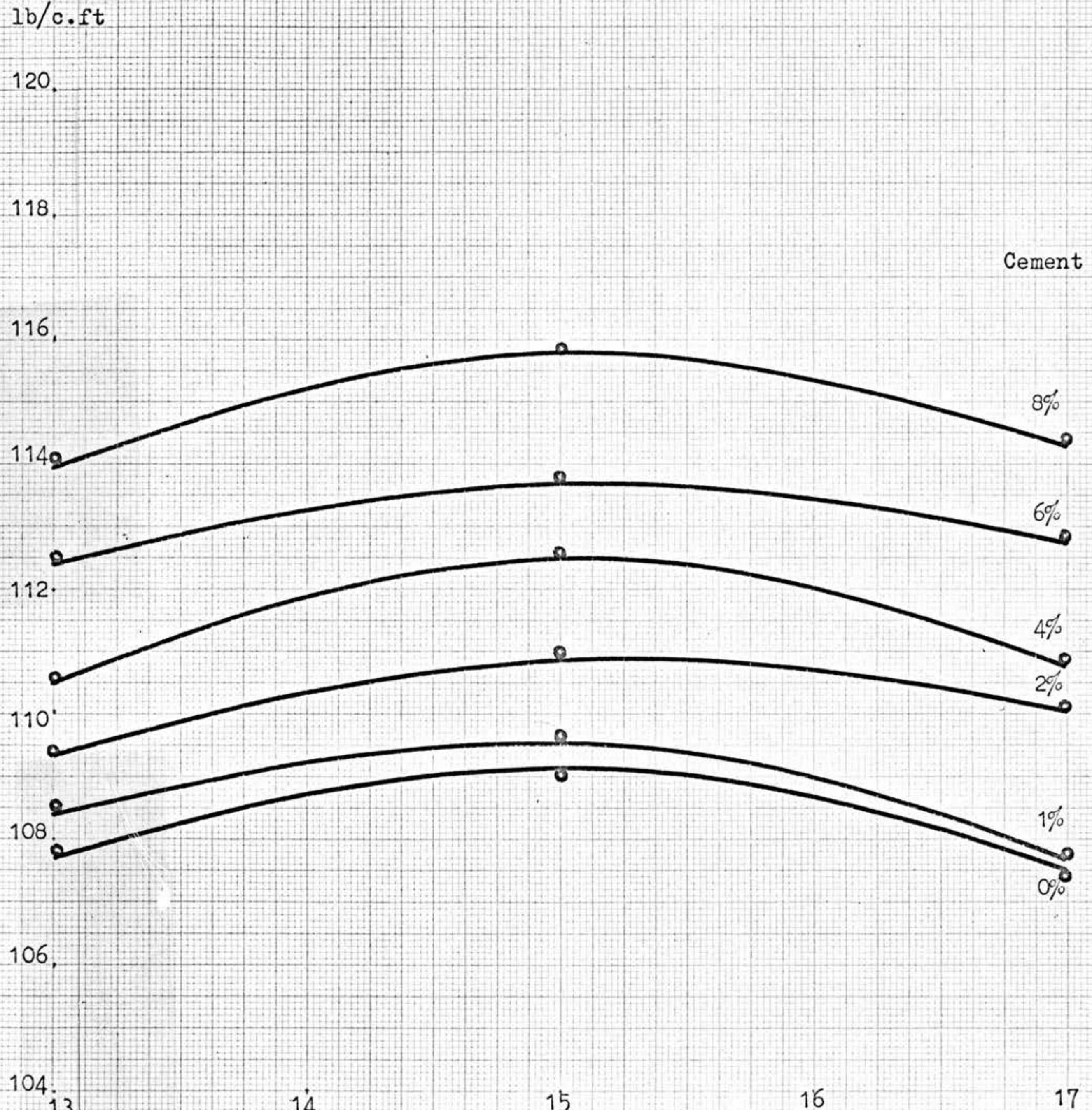


FIG. 33 EFFECT OF MOISTURE OF COMPACTION ON DRY DENSITY

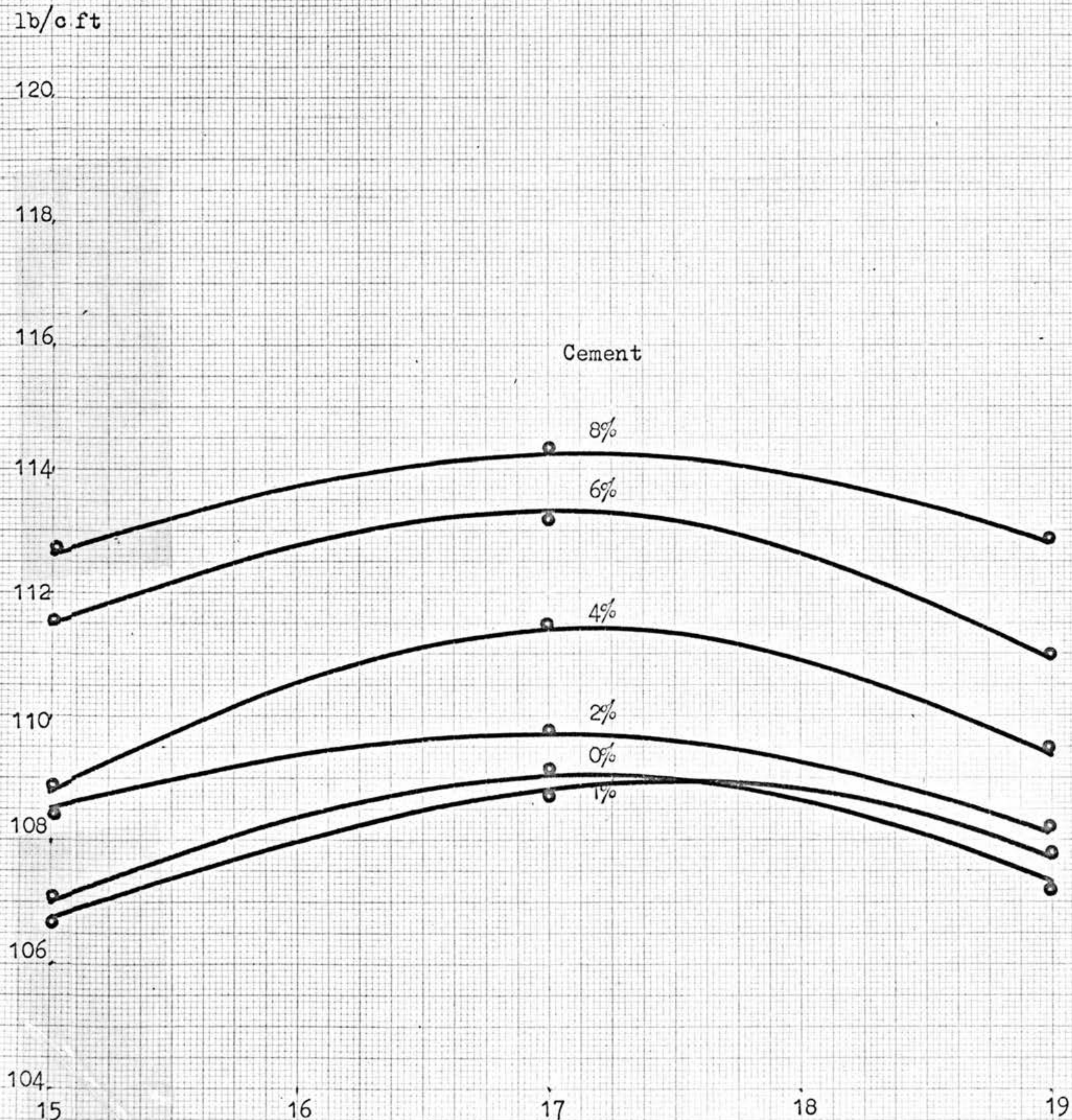
SOIL 4. CHURKANA GROUP



MOISTURE OF COMPACTION PERCENT BY VOLUME

FIG. 34 EFFECT OF MOISTURE OF COMPACTION ON DRY DENSITY

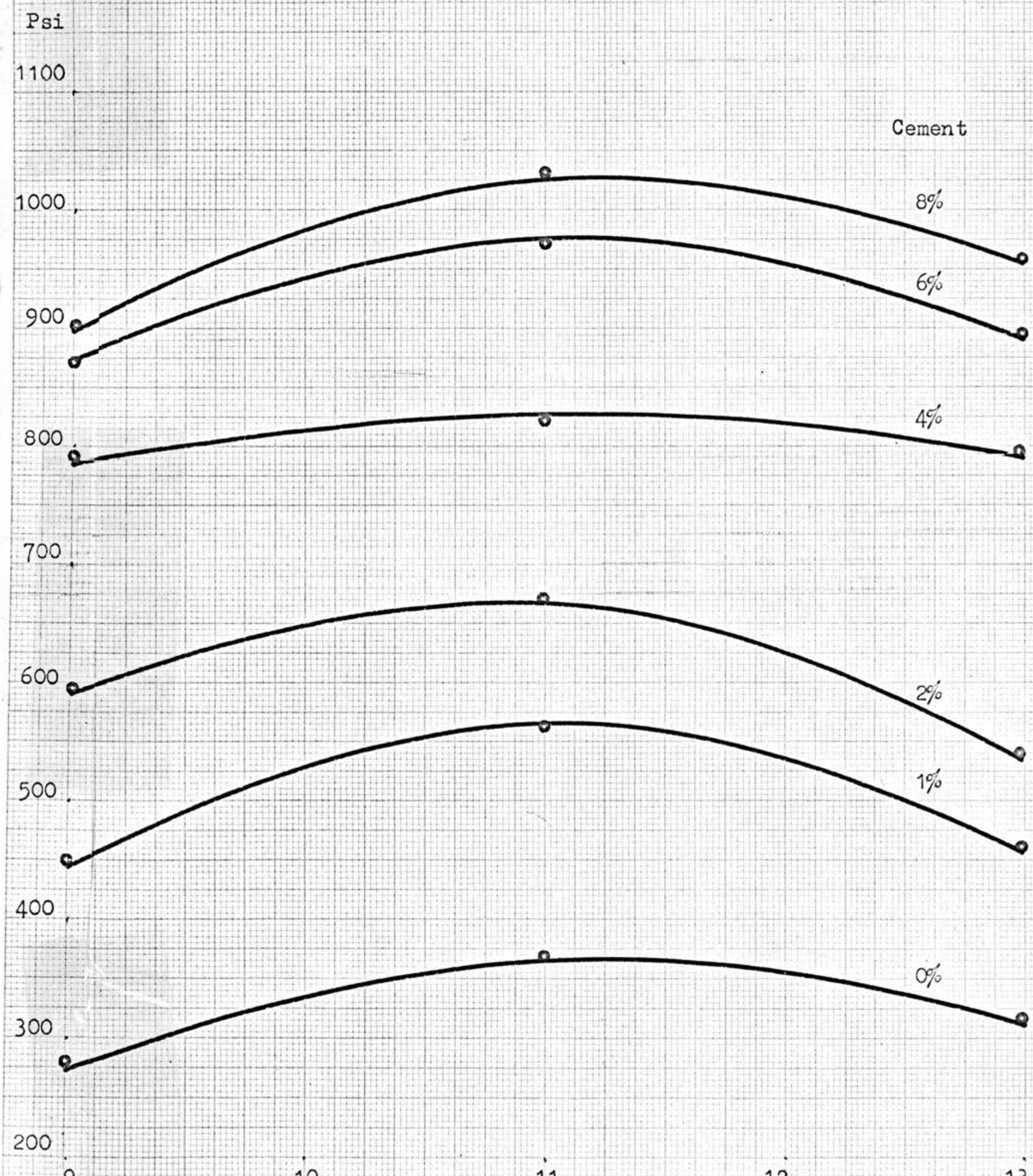
SOIL 5. NOKHAR GROUP



MOISTURE OF COMPACTION PERCENT BY VOLUME

FIG. 35 EFFECT OF MOISTURE OF COMPACTION ON COMPRESSIVE STRENGTH

SOIL 1. JHANG GROUP



MOISTURE OF COMPACTION PERCENT BY VOLUME

FIG. 36 EFFECT OF MOISTURE OF COMPACTION OF COMPRESSIVE STRENGTH

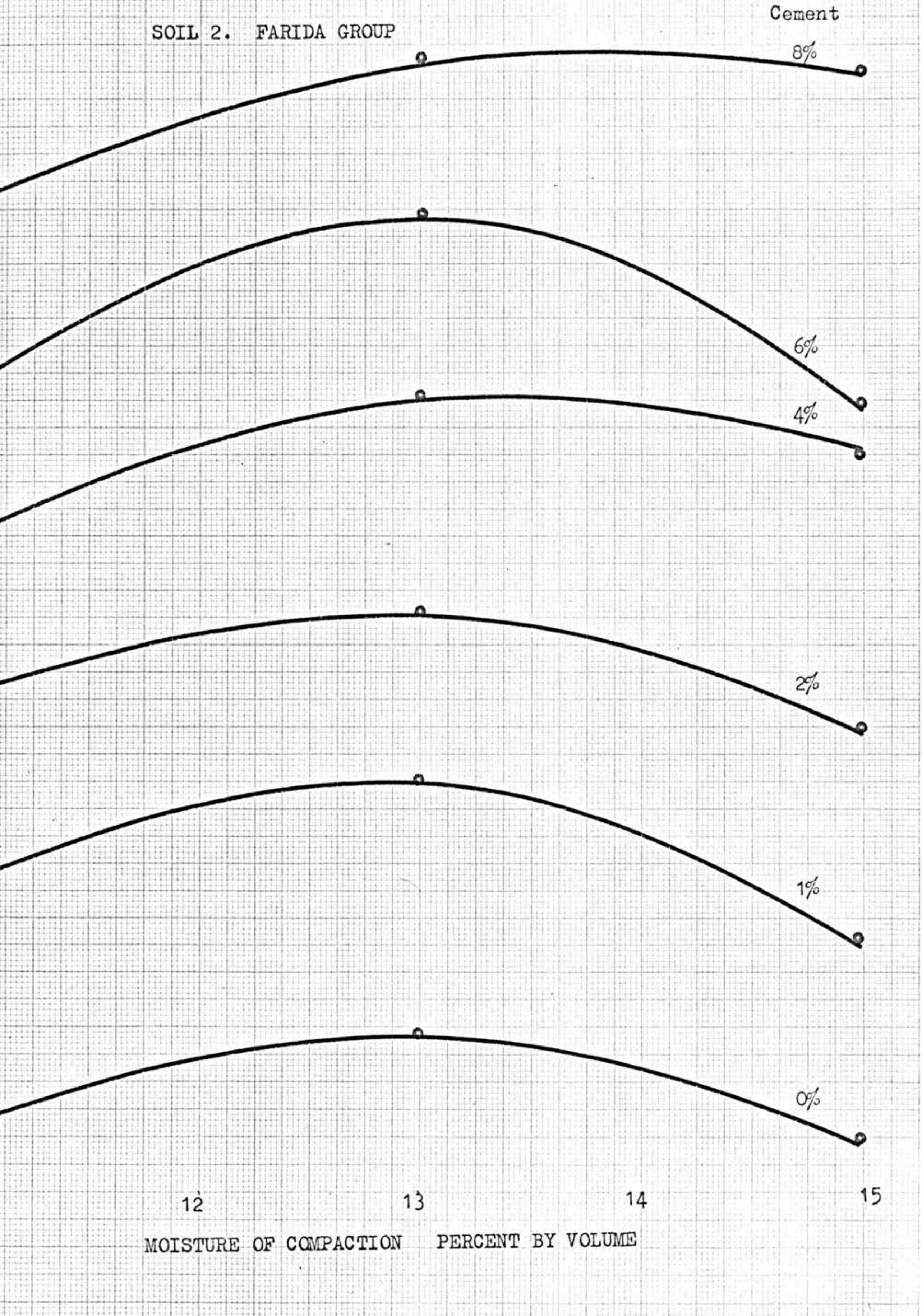


FIG. 37 EFFECT OF MOISTURE OF COMPACTION ON COMPRESSIVE STRENGTH

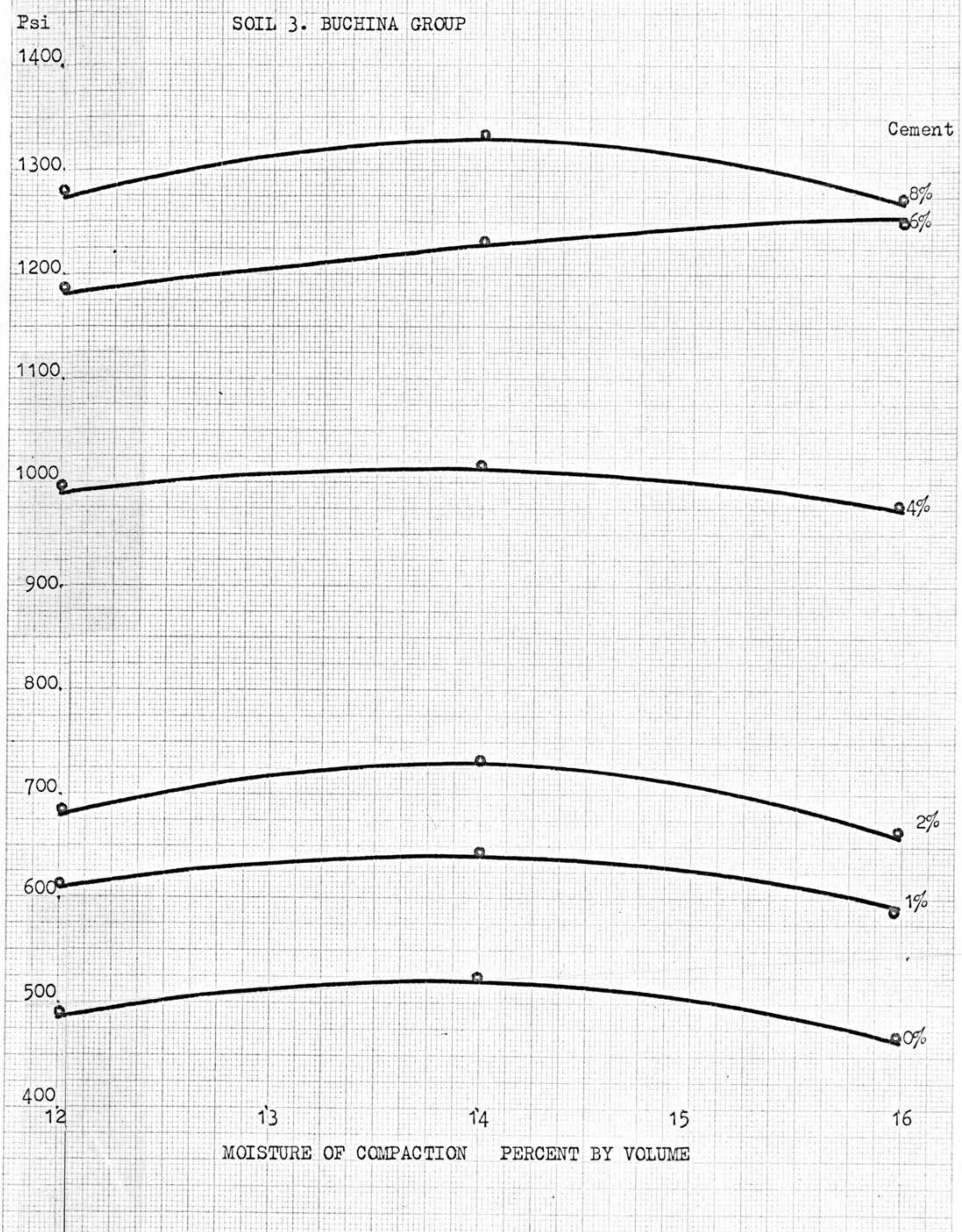


FIG. 38 EFFECT OF MOISTURE OF COMPACTION ON COMPRESSIVE STRENGTH

SOIL 4. CHURKANA GROUP

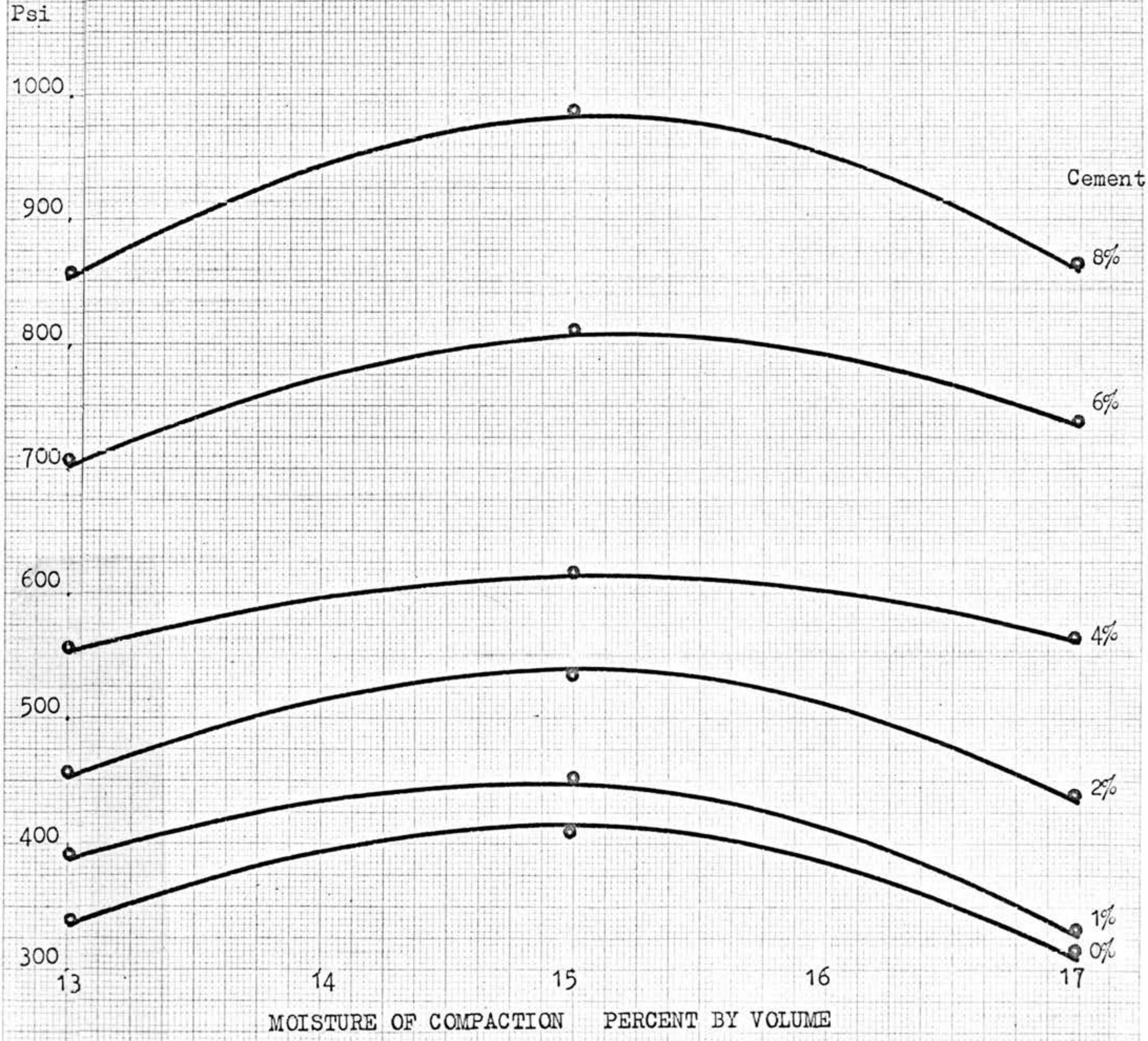
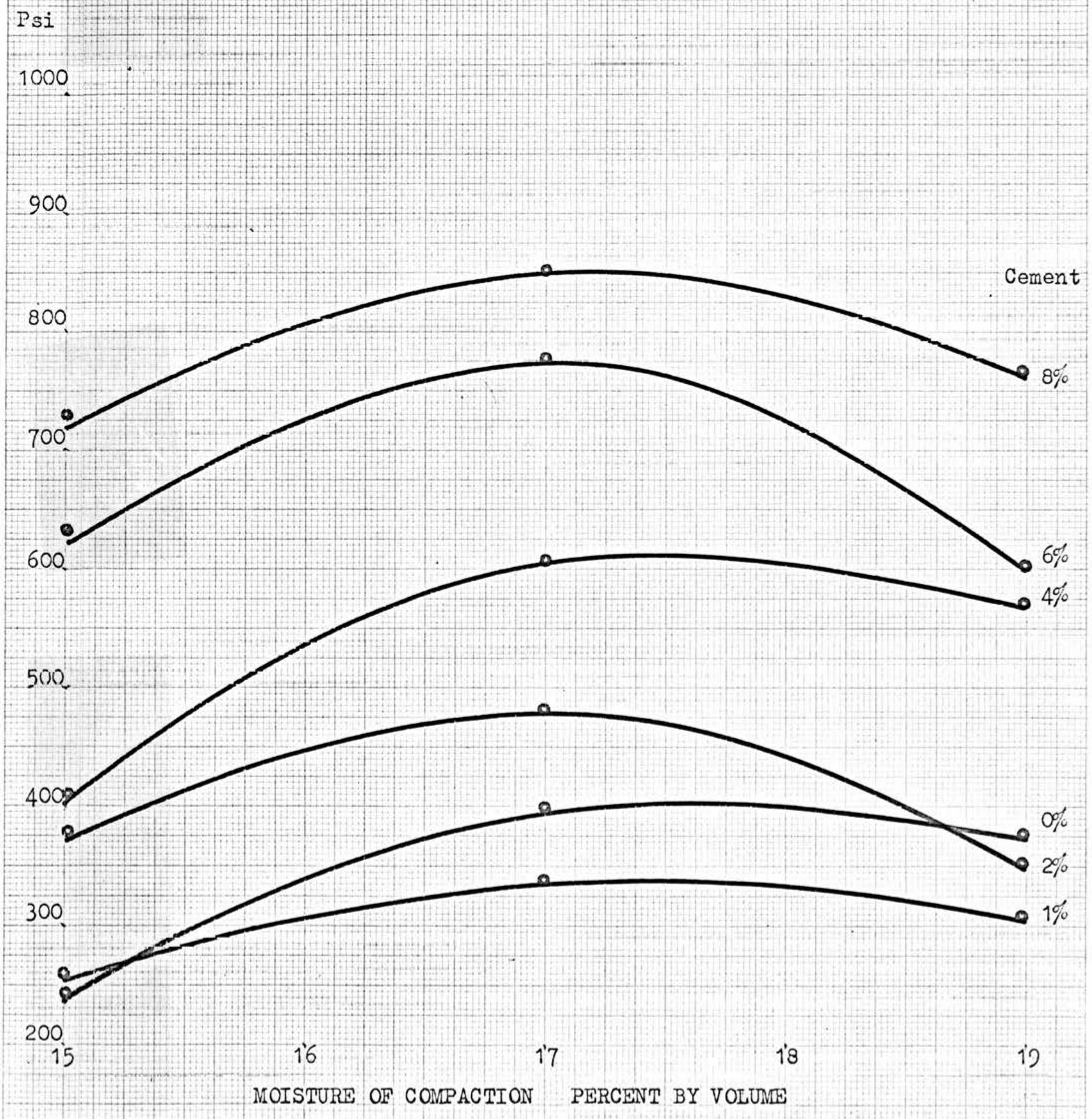


FIG. 39 EFFECT OF MOISTURE OF COMPACTION ON COMPRESSIVE STRENGTH

SOIL 5. NOKHAR GROUP



CHAPTER 9

THE COMPACTION REQUIREMENTS

The preceding tests were carried out on specimens compacted with standard laboratory (rammer and mould) method. The phase of experimentation outlined in this chapter represents an attempt at establishing a relation between the laboratory results to those obtainable in the field, without which this study would have remained but an academic exercise.

It is suggested that simple road making equipment available in all parts of the country and the road making techniques may have a lot to offer to housebuilding on a mass scale. Compaction of the soil panels on their very sites with road roller and tilting them into position with simple mechanism may sound an ambitious idea at present but, given the necessary research background, might form the basis of future stabilized earth house building techniques.

9.1 COMPACTION IN STABILIZATION

Compaction of a soil by the application of a static or dynamic energy is aimed at reducing the pore spaces in natural soil which are normally filled partly with air and partly with water. Due to reduced air voids in the soil structure less moisture would be adsorbed by the compacted soil making it more stable to moisture movements.

Proctor's explanation of the phenomenon of compaction is generally favoured. In his 'theory of lubrication' as it is known, he contends that fine grains are forced into voids between the larger grains. Water is believed to serve as a lubricant reducing the resistance due to internal friction between the soil grains. As the moisture content is increased a point will be reached where the compactive force will overcome this resistance and will cause the fines to be forced into the voids between the larger grains and maximum density will be attained. This is the optimum density at the optimum moisture content which is the lubrication limit under a particular compactive effort. As the moisture is increased beyond this point the compactive force compresses the small volume of entrapped air in the soil mass. This compression gives rise to hydrostatic pressure which tends to separate the soil grains by partial flotation thereby causing a reduction in density.[1]

Apart from this type of initial compaction which may be called primary compaction (or primary consolidation) another type of compaction, denoted as secondary consolidation has also been identified.[2] This type of consolidation occurs throughout the loading period but is most apparent after primary consolidation is essentially complete.[3] Fig.43 shows the effect of this type of consolidation over a period of five years.[4] From the general trend of the curves in this figure it is apparent that much higher values could be expected over longer periods.

9.2 DETERMINING THE COMPACTION REQUIREMENTS

It was not considered necessary to study the effects of varying the compactive effort on the specimens moulded in the laboratory. This

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1. INDIAN ROADS CONGRESS, "Stability of Densified Soils under Adverse Moisture Conditions", Gupta, S.N., 1949, p.212.
2. HIGHWAY RESEARCH BOARD (USA), "Secondary Consolidation", Proceedings 40th Meeting, 1961.
3. PORTLAND CEMENT ASSOCIATION, "Soil-Cement Technology - a Resume", Catton, M.D., Research Department Bulletin 136, 1962, p.19.
4. PORTLAND CEMENT ASSOCIATION, "Tests show Soil Cement improves with Age", Soil-Cement News No.20, May 1946, p.2.

premise was taken because sufficient information existed to conclude that all types of soil with all methods of compaction (i.e. energy applied per unit weight of soil) resulted in an increase in the maximum dry density and decrease in the optimum moisture content.[1] Fig.40 illustrates this point.[2]

In brief, the method involved comparing the moisture/density curves obtained in the laboratory with those obtained with the field compaction method using the same soil, moisture content and cement content.

9.2.1 Equipment

Choosing a method of compaction was a difficult problem because it is dependant to a great extent upon the nature of the building techniques envisaged. The building techniques in turn have to be closely related to the particular circumstances of a site and the level of economic development of the country.

The choice of a road roller for compaction field trials was however not completely arbitrary. Some search into the efficiency of different methods of compaction was made and their respective merits considered.[3] The final choice fell on a smooth wheel road roller because

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1. A detailed investigation of this aspect has been carried out by: AHMED, S.N., "The Influence of Grading and the Energy of Compaction on Density and Strength of Soil-Cement Mixes", Ph.D. Thesis (I.C.), London, 1959.
2. ROAD RESEARCH LABORATORIES (UK), "Soil Mechanics for Road Engineers", H.M.S.O., 1952, p.156.
3. Studies have shown that for a given amount of work the greatest compaction results when the work is exerted in a single application than in dynamic successive applications. It has further been shown that each successive application of the same pressure to the soil results in less and less work per application. (See next page for remainder of this fn.)

of its ready availability, high compaction efficiency and suitability of its use for application of road building techniques to mass stabilized earth housing.

A $2\frac{3}{4}$ ton (British made) smooth wheel roller was used for compacting field panels. This was found to be the common type of roller used for road making purposes by the Public Works Department. Specifications of this roller as provided by the Department are given below.

TABLE 35 SPECIFICATIONS OF THE SMOOTH-WHEEL ROLLER

Total weight	6160 lb
Weight on front rolls	1904 lb
Weight on rear rolls	4256 lb (Total)
Diameter of front rolls	32 in
Diameter of rear rolls	36 in
Width of front rolls	12 in (Each)
Width of rear rolls	15 in
Rolling width	51 in
Load per inch width:	
Front roll	80 lb
Rear roll	142 lb

See:
a) KENNEDY, C.M., "A laboratory investigation of the efficiency of different methods of soil compaction", M.Sc. Thesis (Civil Engg.), Georgia Institute of Technology USA, 1953.
b) HIGHWAY RESEARCH BOARD (USA), "Effect of Repeated Load Application on Soil Compaction Efficiency", by Sowers, G.F., Bulletin 93, 1954, pp.61-64.

The main characteristics of smooth wheel rollers affecting their performance in compacting soil are the load per inch width under the compaction rolls, and the width and diameter of the rolls. The load per inch width and the diameter control the pressure in the surface layer of the soil, while the dimensions of the rolls affect the rate with which this pressure decreases with depth.[1] Thus for compaction work it would be important to specify the load per unit width as well as the gross weight of the smooth wheel roller.

9.2.2 Compaction

Soil encountered at Belianwala site laboratory belonged to Farida group. The site was a flat piece of land with some waterlogging and salinity problem.[2]

The procedure of compacting stabilized surfaces in the field involved marking out an area 9' x 27', scraping away the top 12" layer of soil, ploughing the subsoil to a depth of 12", pulverizing, mixing with cement and water, and finally compacting with roller. Cement content of 2 percent was used throughout. The area compacted was divided into three surfaces separated from each other by wooden battens. Energy of compaction (i.e. the number of passes of the roller) and moisture of compaction were the only variables since the object was merely to determine dry density/moisture content relation with the field compaction. One surface each was compacted with moisture content 11, 13 and 15 percent. Optimum moisture for this soil, as determined

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1. ROAD RESEARCH LABORATORIES (UK), "Soil Mechanics for Road Engineers", H.M.S.O., London, p.179.

2. Soil conditions at this site can be observed from Reference Map 8 in Part IV.

earlier, wqs 13 percent.[1] Compaction was done as a continuous process. Dry density of each surface was determined after 24, 32 and 48 passes respectively. In all, nine such determinations were made which are shown in the following table.

TABLE 36 FIELD COMPACTION RESULTS

Compactive effort (no. of passes of roller)	Moisture of compaction (percent by weight)	Dry density (pounds per cubic foot)
24	11	116.7
	13	115.6
	15	113.1
32	11	119.1
	13	118.2
	15	114.2
48	11	117.8
	13	119.9
	15	120.1

9.2.3 Comparison

Dry densities of all surfaces were obtained using sand replacement method.[2] Dry density/moisture content curves were plotted for each of the three compactive efforts and superimposed on a similar curve for the same soil and cement content obtained with laboratory method.

A comparison of these curves with those obtained in the laboratory for the same soil (Farida) and same cement content (2%) showed that 24

1. See Fig.6.

2. BRITISH STANDARDS INSTITUTION, "Methods of Test for Stabilized Soils", B.S.1924 (1957), Method 5, p.39.

passes of the smooth wheel roller (whose specifications are given in Table 35) would give comparable field results. (See Fig.41).

While comparing the field compaction results with those of the laboratory it must be taken into account that control of pulverization, cement content, water content, mixing and compaction is far more difficult in the field. This means an effective quality control can achieve much better results than those obtained in this study in which pulverization and mixing was done manually. Another significant factor is that field compaction in this investigation was confined to compacting surfaces which would, it is visualized, be used as floors-cum-foundations of the dwellings. In that case the panels to be used as walls would be compacted on this floor surface and later tilted into position. It is therefore evident that degree of compaction (dry density) obtainable in wall panels, compacted on solid floor surface, would be much higher as compared with floor surface compacted without a solid base.

FIG. 40 EFFECTS OF DIFFERENT AMOUNTS OF COMPACTION ON DRY DENSITY

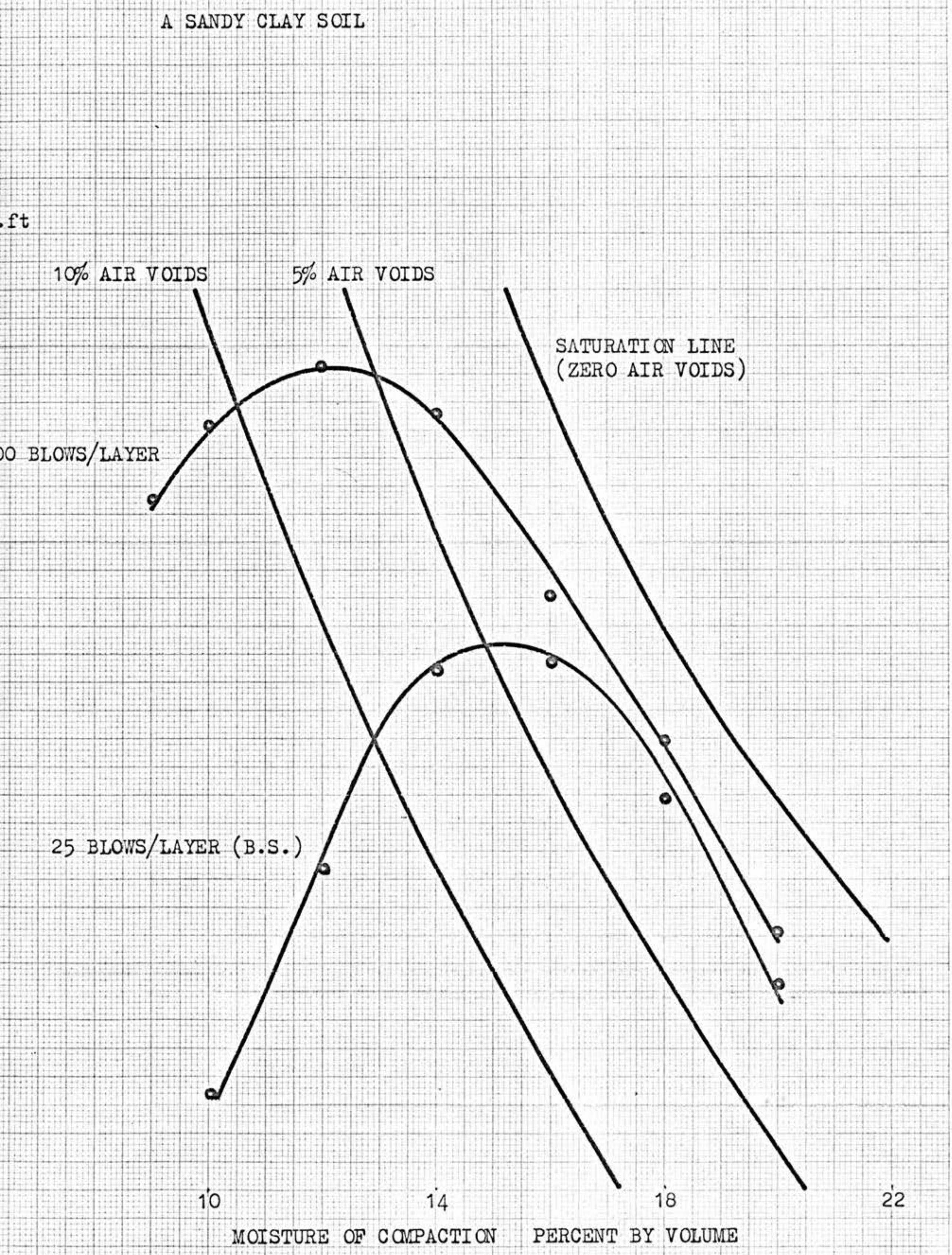
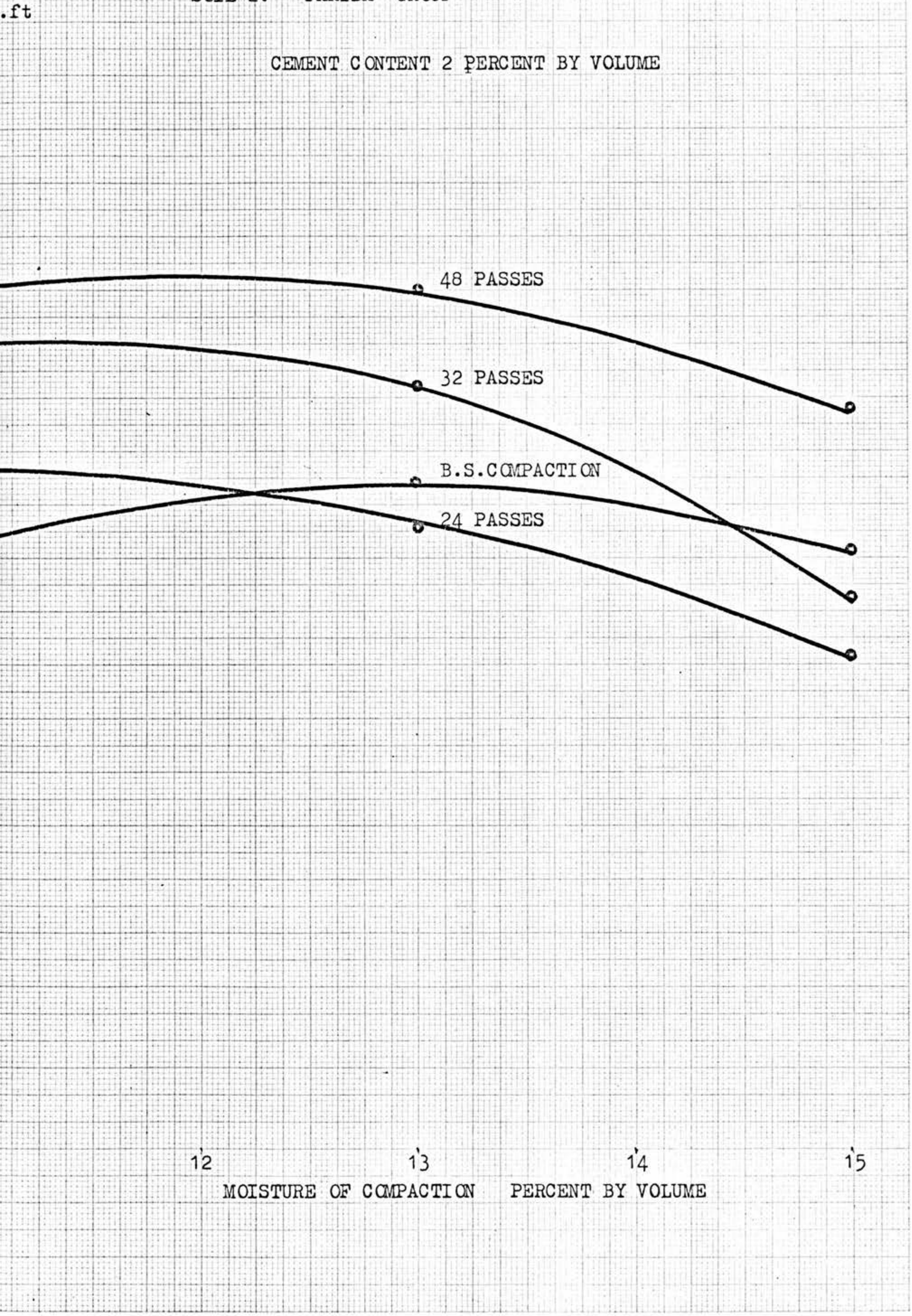


FIG. 41 MOISTURE/DENSITY CURVES WITH ROAD ROLLER

SOIL 2. 'FARIDA' GROUP

CEMENT CONTENT 2 PERCENT BY VOLUME



CONCLUSIONS TO PART III

(Refer to Part IV)

This phase of the study has been concerned with the practical implications of using the soils for building low cost houses in the Thal region. To determine such factors as the suitability of the soils, amounts of cement, moisture and compaction required, a programme of laboratory and field experimentation in soil stabilization was carried out. Each of the five major soil groups was investigated from this viewpoint and results compared with those of burnt clay brick. The following general conclusions may be derived from this experimental phase.

a) All the five major soil groups found in the area under consideration can be stabilized effectively. Results obtained of course varied with each soil group due to their textural composition; more profoundly the amount and type of clay present. Basically sandy soils with just enough clay to fill their voids gave the best performance in all four test series.

b) Sufficient performance level for normal housing requirements should be attainable in most cases with a maximum of 2 percent cement. In soil groups with less favourable constitution and grading this amount may have to be increased slightly. The following table compares the results of weathering test for all soils with a poor quality and medium quality burnt clay brick; no other suitable criteria for this purpose being available.

TABLE 37 COMPARISON OF PERFORMANCE WITH BURNT BRICK

Material		Weight Loss (percent, after 12 cycles)
Soil 1	2% cement	8.1
	4%	5.7
	8%	1.5
Soil 2	2%	4.6
	4%	3.2
	8%	0.8
Soil 3	2%	6.1
	4%	4.4
	8%	1.1
Soil 4	2%	13.4
	4%	5.8
	8%	2.9
Soil 5	2%	11.3
	4%	7.4
	8%	4.2
Burnt)	Poor quality	6.2
Brick)	Medium quality	0.9

It is recognized that the terms used to define the quality of burnt brick in Table 37 are rather arbitrary as far as their actual long term performance in the field is concerned. It was however difficult to assign them a more scientific criteria than that of their weight loss in the accelerated durability test; supplemented by a general observation of their past behaviour in the field. 'Poor quality' brick is most commonly used for low-cost housing purposes. Some houses in this category built 50-60 years ago have shown no serious signs of weathering.[1]

1. These houses were built by The Attock Oil Company for its lowest grade employees at Morgah, about 6 miles from Rawalpindi.

c) The natural moisture in the soil, ranging from 2-4 percent, was far too short of the optimum moisture requirements. The natural moisture contents would be much higher in rainy season; during certain periods even higher than optimum. But such periods are infrequent and of short duration. Optimum moisture requirements varying between 11-17 percent could easily be met from canal water which through a network of distributaries reaches almost every acre of cultivated land in the area.

d) The compaction obtained in the laboratory with the Standard B.S. method of 25 strokes of a 5.5 lb rammer would need to be related to whatever method of compaction is proposed in the field. This study relates it to a $2\frac{3}{4}$ ton smooth-wheel roller whose 24 passes gave comparable results. The comparison with any other method should not prove to be difficult. Moisture/density curves obtained with the proposed method of field compaction can be related to the laboratory curves given in this study for the same soil group.

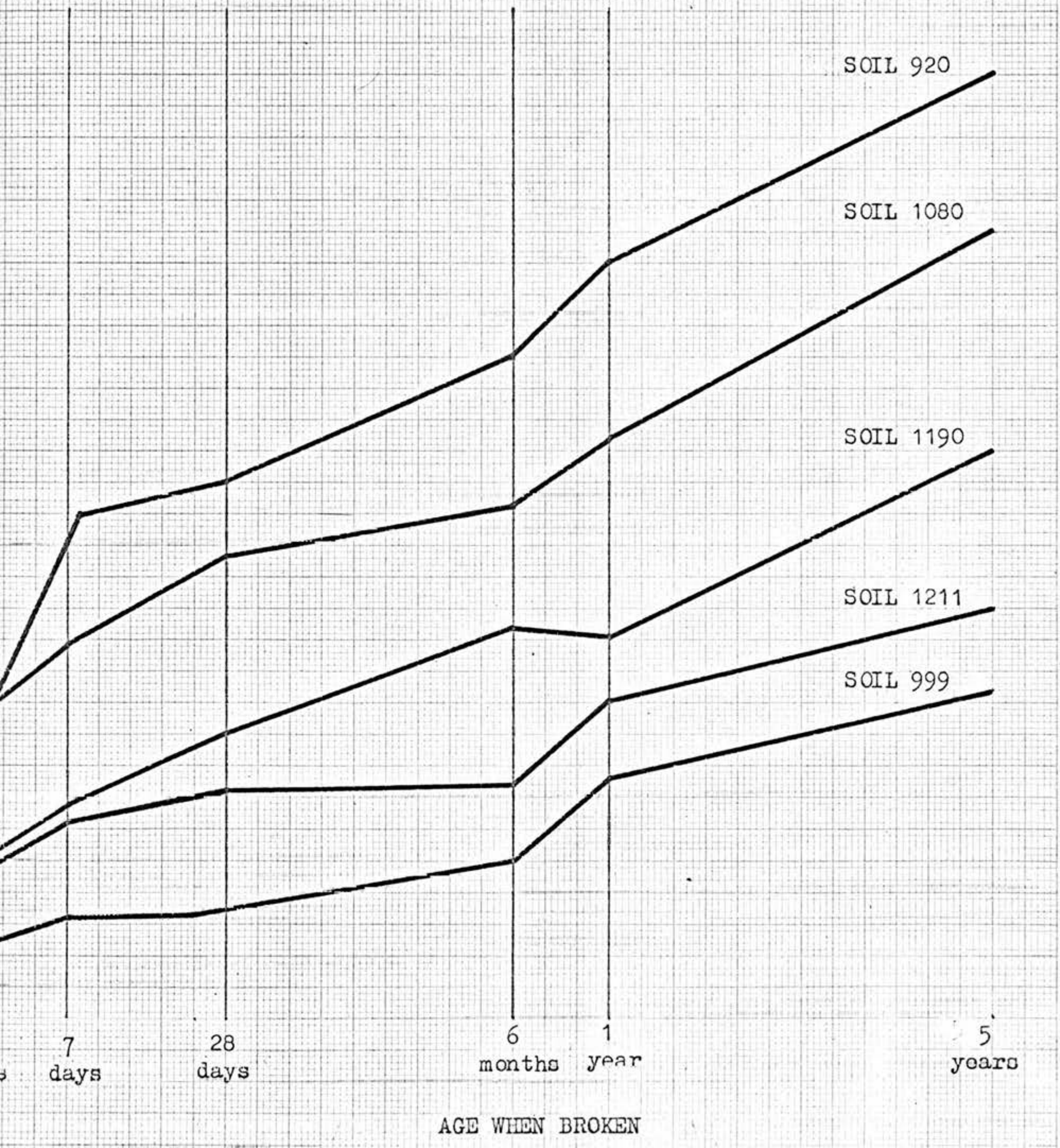
e) Compressive strength and dry density indicated almost a direct relationship (see Fig.42).

f) Another favourable factor worthy of consideration is the contention that the compressive strength of the compacted soil-cement increases with age (see Fig.43).

FIG. 42 RELATIONSHIP BETWEEN DRY DENSITY AND COMPRESSIVE STRENGTH

FIG. 43 EFFECT OF AGE ON COMPRESSIVE STRENGTH

(U.S. SOILS)



PART IV

PLANNING THE RESOURCES FOR STABILIZED EARTH HOUSING

PART IV

PLANNING THE RESOURCES FOR STABILIZED EARTH HOUSING

This concluding part in essence represents the whole spirit of this study, derived from and based on the findings of the preceding sections and presented in simplified and graphic form. The use of words has been kept to the barest minimum so as not to hamper its utility as a ready reference.

REFERENCE : 1 SURFACE RELIEF MAP

Information about the general physical characteristics of an area provided by this map should help in a preliminary assessment of the soil resources.

Colours on the map indicate the height above sea level of any particular area. The northern mountainous region (known as Snow Forests) has high altitude and is least likely to have sufficient quantities of soil to encourage earth housing. On the other hand the Indus Plains abound in suitable soil.

This map also gives a general idea about the landscape of a region. Too frequent changes in colours on the map indicate abrupt changes in the level of the ground. This has some influence on the building techniques to be adopted. For example application of road making techniques to mass housing requires a relatively flat stretch of land.

This map also serves as a general reference showing the region investigated and other geographical details.

REFERENCE : 2 EXPOSURE CONDITIONS MAPS

Greater economy apart from comfort in stabilized soil structures can result if the material is stabilized and used in consideration of the degree of exposure to driving rain expected in the area.

Like most other functional requirements of buildings the exposure conditions can also be expressed in quantitative terms. The rainfall and the direction and speed of the wind during rainfall may be used as the basis.[1] Given this information it is possible to indicate the amount of rainfall that would be driven in one year to a vertical surface always facing the wind.[2] This in turn will be the basis for the measure of the durability of the material.

It needs to be pointed out that data about the speed of the winds was not available. It is not therefore possible to provide an 'index' of driving rain for each area. The use of this map can however be made by corelating the frequency of the winds with that of the rainfall. This corelation, considered in conjunction with the wind direction during that period, should help considerably in determining exposure conditions in a region.

Taking the region whose soils have been investigated in detail, as an example, the following points may be noticed from the exposure maps prepared for this section:

a) The area under consideration (Thal) lies in climatic zone 4 (sub-tropical plains) whose annual rainfall ranges between 10-20 inches.

b) The total rainfall in 24 hours at times may be as much as 8 inches in some places.

c) The direction of the prevailing winds, as seen from the records of the Meteorological Centre at D.I.Khan, is almost throughout the year from the north.[3]

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1. BUILDING RESEARCH STATION (UK), "An Index of Exposure to Driving Rain", Building Research Station Digest 23, H.M.S.O., 1962.

2. For method of preparation of maps showing annual driving rain index see METEOROLOGICAL MAGAZINE, "An Index of Driving Rain", by Lazy and Shellard, vol. 91, 1962.

3. The nearest meteorological centre from the area under detailed investigation was Dera Ismail Khan (K.I.Khan). Maps in this section are based on data provided by BUILDING RESEARCH STATION (PAKISTAN) and ATLAS OF METEOROLOGY.

d) The most of the rainfall occurs within a short period of the Monsoon, and in the form of a few heavy downpours. The Monsoon season generally lasts from June to August.

e) The frequency and intensity of the winds is also at its peak during this short period.

The above mentioned derivatives lead to the inference that walls facing north in this area will be subject to much more severe exposure to driving rain as compared with other walls.[1] It is, therefore, necessary to give particular attention to walls facing north in this area not only in design and layout but more so in the actual process of stabilization. Considerable economies may be achieved by using relatively less cement content for walls facing directions other than north and in other sheltered positions. In such cases the criteria would mainly be compressive strength and not resistance to weathering by rain. All soils were found to achieve considerably high compressive strengths with small amounts of cement.[2] In fact minimum compressive strength criteria are satisfied even without any addition of cement, by compacting the soils at their optimum moisture.

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1. Notice this in Plates 41 and 47, Chapter 2. These pictures were taken immediately after a heavy downpour. It is noticed that walls facing north have almost exclusively borne the fury of the driving rain. Some wetting of walls facing other directions has taken place mainly due to faulty parapet design or due to rainwater falling on thick parapets and flowing to outer surfaces.

2. As noticed in the results of experiments in Chapter 7.

REFERENCE : 3 GENERAL SOIL MAP

This map is an attempt at generalizing the soil characteristics brought out by the results of the analysis of over one hundred thousand soil samples through an extensive survey of West Pakistan. This survey has primarily been for agricultural purposes but effort has been made to prepare a general map useful as preliminary reference from stabilization point of view.[1]

REFERENCE : 4 GENERAL WATER TABLE MAP

This map shows contours of existing ground water level based on the investigations carried out over a period of years.[2] This map is intended to provide a preliminary idea about the conditions likely to be met in a particular region where soil stabilization is envisaged.

REFERENCE : 5 GENERAL SALINITY MAP

Excessive quantities of salts in soil have been found to inhibit the effective stabilization of soils with cement. A general map based on the criteria set out in Chapter 3 (Table 23) and data provided by the Soil Reclamation Directorate, may help identify areas in the danger zone.[3]

REFERENCE : 6 GENERAL GROUND WATER QUALITY MAP

Ground water in most cases would have to be used for meeting the moisture requirements for the stabilization process. A general

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1. This map was prepared from the data collected by the UNITED NATIONS SOIL SURVEY PROJECT, Lahore, West Pakistan.

2. Survey carried out by the WATER AND POWER DEVELOPMENT AUTHORITY OF PAKISTAN, Water and Soil Investigation Department.

3. SOIL RECLAMATION DIRECTORATE, Lahore, Government of West Pakistan, Investigations carried out for the purposes of 'reclaiming' the soils affected by presence of salts.

information about the dissolved salt content of this source should therefore prove a useful guide in planning an earth housing project in a region.[1]

REFERENCE : 7 SIMPLIFIED FIELD TEST CHARTS

The last phase of this manual deals with the application of the resource planning to a particular site. The first task is that of locating a particular site correctly on the Reference Map 8 so as to be able to make use of the information provided by this map. In most cases it will present no problem but doubt may arise in case of some borderline sites. In such situations simple soil tests for use in the field although approximate, should prove acceptable enough as a basis for relating the soil encountered at any particular site to the major soil groups shown on Reference Map 8. Through this relationship the layman can predict with reasonable accuracy the behaviour of any soil when stabilized with cement. It must, however, be recognized that these simplified tests are recommended for situations where laboratory testing is impracticable. For important or larger projects laboratory tests must not be dispensed with since upon an accurate identification of the soil depends the ultimate effectiveness of the soil stabilization.

The following simplified soil identification methods are suggested for the purpose of determining the percentages of the basic components in the soil and consequently the major soil group to which that particular soil belongs.

FIELD TEST CHART 7 A : VISUAL EXAMINATION

This gives an idea of the proportion and size of the coarse granular components (very coarse, medium, coarse, medium and fine sands)

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1. Ibid.

and, by inference, of the fine particles (silt and clay), since the smallest particles visible to the naked eye are those of fine sand.[1]

FIELD TEST CHART 7 B : TESTING BY TOUCH

The feel of a soil when ribboned between the fingers can also help identify its basic components with some accuracy.

FIELD TEST CHART 7 C : SQUEEZE TEST

The effect of applying pressure on a soil in both dry and moist state by squeezing in the hand has also been found to indicate the proportions of its constituents.

FIELD TEST CHART 7 D : RIBBON TEST

The success of an attempt to make a thread of moistened soil will depend on its plasticity which in turn reflects its constitution.

FIELD TEST CHART 7 E : SEDIMENTATION TEST

This test supplements the preceding ones and indicates the proportions of the basic soil components with greater accuracy.

FIELD TEST CHART 7 F : SEPARATION TEST

This test is used to distinguish fine sand from silt or clay which would not have been achieved to a desirable degree in the preceding tests.

FIELD TEST CHART 7 G : DRY STRENGTH TEST

This test is also based on measuring the plasticity of the soil which is a function of the proportion of its basic components. This test is particularly useful in determining the finer fraction i.e. fine sand, silt and clay in the soil.

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1. UNITED NATIONS, "Soil-Cement, its Use in Building", Department of Economic and Social Affairs, New York, 1964, pp.7-12.

REFERENCE : 8 DETAILED SOIL MAPS

These maps are prepared by combining the information obtained from different sources about the soils in the Thal region. Information about the textural composition of the soils is derived from the results of the soil survey carried out by the United Nations Soil Survey Project, Lahore.

The method adopted for the preparation of these maps involved the following steps.

a) Tracing of all 'Base Maps' showing locations of all bore holes from which samples were taken.[1]

b) Allocating soil group to each soil sample based on its textural composition.

c) Marking the soil group of each sample on the location of its respective bore hole on the map.

d) Joining the points on the map (representing bore hole locations) having same soil groups.

e) Plotting other information like groundwater level and salinity on these maps. This information was obtained from Soil Reclamation Directorate, Lahore.

f) Reducing these maps to (1:60,000), one tenth of their original scale.

These maps in a very comprehensive yet simplified form represent the ultimate in this study. They provide nearly all the information needed for undertaking a stabilization project - however mean or magnificent.

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1. These 'Base Maps' drawn at a scale of 1:6,000 (1" = 500') were used originally in the soil survey as described in Chapter 4.

This information consists of:

a) Surface relief.

b) Surface texture (depth of soil 0-1.5 ft).

c) Sub-soil texture (depth of soil 0-6 ft).

d) Sub-stratum texture (depth of soil 6-10 ft).

e) Ground water conditions.

f) Salinity.

The cement requirements for achieving results comparable with burnt brick have been found to range between 2-4 percent by volume as shown in the following chart.

STABILIZED EARTH REQUIREMENTS CHART

Soil group	Cement requirements (Portland cement % by volume)	Water requirements (O.M.C. % by volume)	Compaction requirements (dry density lbs/c.ft)	Durability (weight loss % after 12 cycles)
1. Jhang	2	11	112	8.1
	4		114	5.7
2. Farida	2	13	116.3	4.8
	4		119.3	3.2
3. Buchina	2	14	112.8	6.1
	4		116.3	4.4
4. Churkana	2	15	110.9	13.4
	4		112.5	5.8
5. Nokhar	2	17	109.8	11.3
	4		111.4	7.4
		'Poor' quality brick[1]		6.2
		Medium quality brick		0.9

1. For definition of 'poor' quality brick see Conclusions to Part III.

The amount of water to be added can be calculated by subtracting the natural moisture from the optimum moisture from the above chart. The natural moisture content in the soil during any particular time of the year can be easily determined by simple means.

The amount of compaction achieved would depend upon the choice of the method of compaction relevant to the techniques of construction envisaged. The only requirement to be met is that results achieved should be comparable to the standard laboratory compaction used in this study. This comparison can easily be obtained by relating the Moisture/Density curves obtained with the proposed method of compaction to the similar curves obtained in this study with the laboratory compaction. This objective can also be achieved by simply comparing the density achieved in practice with the density given in the above chart for the same cement content and same soil group.

Once these basic requirements are known, construction in stabilized soil can be carried out in a variety of ways ranging from monolithic to block construction. The most favoured of the present monolithic wall construction techniques involves compacting this material with pneumatic rammers in roller supported moveable forms. A UN Manual describes this method in detail.[1] As far as block construction is concerned the technique is no different from building in traditional materials like brick or concrete block. Another UN handbook gives detailed guidance for construction in stabilized soil blocks.[2] Until more work is done about using this material in other more promising ways the constructional procedures laid down in these manuals must be strictly adhered to.

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1. UNITED NATIONS: "Manual on Stabilized Soil Construction for Housing", by Fitzmaurice, R., New York, 1958.

2. UNITED NATIONS: "Soil Cement, its Use in Building", New York, 1964.

CONCLUSIONS TO THE STUDY

The scope of this study has been limited to the extent of showing that the soils of West Pakistan can be effectively stabilized; and that of providing means by which initial decisions about feasibility at a given site could be taken without testing of the soil, and subsequent testing greatly reduced. Use of the Reference Maps as such can also be made for small projects or isolated house building operations with some assistance from the government in helping interpret the findings of this thesis as presented in Part IV.

Development of a new material also leads to questions about the possible forms of its use in actual construction. These concluding pages therefore attempt not only to summarise the prominent findings of this study but also outline some of these related aspects of the use of stabilized soil in house building.

A. Suitability of stabilized soil for house construction

a) High costs of existing materials, transportation difficulties and lack of finance at government and individual level necessitate that attention be focused on the development of soil as a material of construction.

b) Practically all soils in the Indus Basin can be effectively stabilized with Portland cement. Sandy soils having just enough silt to fill the voids and sufficient clay to bind the particles together give best results. The soil groups falling into this category are also the most widespread in the Indus Basin.

c) Stabilized soil has acquired a reputation as an excellent construction material. Its use is rapidly increasing in all countries especially in rural and suburban areas. Success of the soil cement projects in other countries was not however taken as a sufficient guarantee of the success of this material in the Indus Basin because of the differences in soil type and climate. The closest project to the region under investigation is in East Panjab, India, where this material has been used with complete success (see below).

Determination of actual long term field performance of stabilized soil in housing is a tricky problem. Various research workers have fallen into the fallacy of recommending weight loss in the laboratory tests as criteria for long term field performance. This kind of approach has resulted in utter confusion on account of great disparity in the criteria advocated by different authorities.[1]

In theory at least, a method involving the construction of prototype houses in the region with the soils under investigation and observation over years of use would be the ideal test of field performance. This unfortunately was impracticable in a study of this nature. An indirect approach was therefore adopted to achieve the same objective. This involved comparing the performance, in the accelerated durability test, of stabilized soil and burnt brick, and then observing the actual long term field performance of the houses built with similar brick.

Performance of different soils in the accelerated durability test, depending upon their constitution and the amount of cement used, varied between that of a 'poor' quality and 'medium' quality brick.[2] Three specimens each of poor and medium quality brick, taken at random from the representative piles at a particular kiln, were subjected to test for

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1. MARKUS, T.A., "Design Techniques for Earth Housing", M.Arch. Thesis, M.I.T. (USA), 1955.

2. Farida and Buchina groups with 2% cement gave better results than poor quality brick. The other three groups give similar results with 4% cement.

comparative purposes. The weight loss in the test for each of the three samples was almost exactly the same (6.2% for poor quality and 0.9% for medium quality brick). In view of this evidence the variation in durability due to factors associated with manufacture of the bricks were taken to be negligible. It was for this reason that only three representative specimens for each quality of the brick were used for control purposes.

A housing scheme consisting of 232 low-cost detached dwelling units built with 'poor' quality brick (taken from the same kiln from which control specimens were obtained) was selected for observing the field performance of this particular type of brick. This scheme was built some fifty years ago for the Attock Oil Company near Rawalpindi and was large enough to enable meaningful conclusions to be reached about the performance of the brick as used in individual dwellings. The scheme was studied in detail and occupants of all the houses (about fifteen in number) which showed some signs of weathering of the brick were interviewed. None of the residents had complaints attributable to the loss of durability of the brick.

Assuming the validity of the basis of this correlation, such field performance may also be expected from stabilized soil; but it would be desirable to build a small number of experimental houses with soil cement in order to make the correlation of field performance in building more reliable.

d) It was not possible to obtain data to make a cost comparison of this material with brick or any other material meaningful. Costs are quoted in several publications on the subject but the basis of the cost is rarely if ever described; and there is no separation of labour, material and plant costs, nor is it stated whether or not overhead charges and profits of the contractor were included.[1] Efficiency of the organization contributes greatly to the results obtained, and this varies from site to site. The skill of the operatives and the amount of effort they put into their work are also extremely variable. Consequently the real validity of such comparisons is highly questionable.

The economics of any type of construction in stabilized soil are therefore an involved process that must be considered by the builder for the prevailing set of circumstances. The following simple statement can however be made, in isolation from other factors, to give some idea of the economies possible with soil stabilization: The total quantity of cement required per cubic foot of stabilized soil walling (with 2.5% cement) equals the quantity of cement required for laying the same volume of brick walling.[2]

B. Suitable method of compaction

All available methods of compaction can be classified under the two basic forms of compaction, dynamic or static. Studies have shown that for a given amount of work the greatest compaction results when the work is exerted in a single application rather than in dynamic successive applications.[3] It has further been shown that each successive application of the same pressure to the soil results in less and less work per application.

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1. Estimates of cost for building 100 cu.ft of walling vary from £4.30 (Rs.60) in India to £10.40 in Australia.

2. UNITED NATIONS, "Manual on Stabilized Soil Construction for Housing", by Fitzmaurice, R., New York, 1958.

3. See footnote 3, page 111.

The equipment used for compaction depends upon the nature of building techniques envisaged. A brief discussion of each type of equipment relative to their respective methods of construction can however be attempted.

a) Hand rammers can be used for monolithic walls of stabilized earth in moveable forms as well as for ramming blocks in simple moulds. Rammers, both with steel and wooden heads, have been tried though the former are more common. The best shape for a rammer head has not been recently investigated but tests done some time ago in America showed that a flat rammer head gave better compaction than a pointed one.[1] A rammer with 14-18 lb weight and with 3-4 inches square steel head welded to a five or six foot length of 1-1½ dia. piping has been found to give best results.[2] With manual ramming, marked variations in the strength of compacted soil-cement are likely, for this varies with the compactive effort applied, the time taken and labour expended. This method may be used in remote areas where labour is either very cheap or the building is on a self-help basis. Three manhours are required for manual ramming of a wall section of 12 c.ft.

b) Compressed air rammers can be used with great advantage where some capital investment in such equipment is feasible. Tests carried out at the Commonwealth Experimental Building Station, Australia, have shown that best results are obtained using a 23 lb modified sand tamper with a 6 inch square head operated by compressed air at 70 lb per sq.in and working 160 strokes per minute.[2] The density achieved is far more uniform

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1. AGRICULTURAL EXPERIMENTAL STATION (South Dakota, USA): "Rammed Earth Walls for Farm Buildings", by Patty, R.L. and Minium, L.W., 1945.
2. COMMONWEALTH EXPERIMENTAL BUILDING STATION (Sydney, Australia): "Earth Wall Construction", by Middleton, G.F., 1952.

and the ramming time is reduced to $1\frac{1}{2}$ hours for 12 c.ft - half the time taken for manual ramming. Compressed air rammers can be used with great advantage for intermediary situations where a project is large enough to justify some capital investment in such equipment.

c) Compaction machines for the production of stabilized soil blocks work on one or other of two principles: either a constant pressure is exerted on the soil-cement mix or it is compacted to a constant volume. In either case it is necessary that the correct amount of soil-cement is fed to the machine. If less than this is used, a smaller block is produced, with the constant pressure machine, while a block of reduced density - and thus reduced strength and durability - will be made by the constant volume machine. In all cases, therefore, the use of a gauge box should be made to contain just the correct amount of the mix determined by prior experiment.

i) The simplest and most favoured constant-volume machine is CINVA-RAM Moulder developed by the Inter-American Housing and Planning Centre, Bogota, Colombia.[1] The CINVA-RAM operates on the principle of an infinitely varying lever arm which develops high pressures on the blocks. It is operated manually by two persons, weighs only 140 lbs and is relatively maintenance-free. A comprehensive testing programme was accomplished during the development of the machine and excellent results were reported.[2] The soil mix in the moulding box is compressed at a pressure of about 300 lbs/sq.in.

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1. CINVA-RAM is now also manufactured in the USA by Richmond Engineering Co., Richmond. The selling price in USA is 175 dollars.
2. <u>CIVIL ENGINEERING</u>: "Soil Cement for House Construction", by Stone, R., Vol.22, p.1005, Dec.1952.

ii) The LANDCRETE is another successful machine exploiting the principle of lever arm.[1] This is operated by two hand levers which push upwards the bottom plate of a metal mould filled with loose soil-cement mix compressing it against a locked top plate. The top plate is then opened and levers reversed, causing the bottom plate to push the compacted block out of the mould. Two persons are required to operate the machine producing about 120 blocks per hour. A pressure of about 400 lbs/sq.in is exerted on the soil-cement mix.[2]

iii) The WINGET blockmaking machine is a hydraulic press powered by a gasoline engine.[3] It has a rotating table with three operating positions for mould filling, pressing and ejecting. This table is rotated manually so that the rate of production is controlled by the operators. The rate of production is the same as for hand operated machines but the quality of blocks produced is good, due to a high operating pressure of about 1000 lbs/sq.in.[4]

d) It is evident that if the housing problem in the country has to be tackled on realistic grounds a mass house building programme would have to be launched as soon as possible. It is envisaged that roadmaking techniques, given the necessary research backing, may have a considerable contribution to make in this field. The possibility of the use of road rollers was therefore investigated in this study. 24 passes of a $2\frac{3}{4}$ ton smoothwheel roller gave comparable results with those obtainable in

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1. The LANDCRETE is manufactured by Messrs Landsborough Findlay (S.Africa) Ltd., Johannesburg.
2. BUILDING MATERIALS RESEARCH INSTITUTE (Rangoon, Burma): "Rammed Earth and Stabilized Soil for Building Construction", by Rosenak, S., 1957.
3. The WINGET is made by Messrs Winget Ltd., Rochester, England.
4. TEXAS TRANSPORTATION INSTITUTE: "Darthen Home Construction", 1962.

standard laboratory compaction. The choice of this method of compaction for the purposes of this study must on no account be taken to mean that the other above mentioned methods were found to be ineffective. Suitability of any particular method of compaction at any given site would depend upon the prevalent physical and economic factors, in particular the scale of the building programme.

The idea of the application of road making techniques to mass housing, however, needs a great deal of further investigation before it can become a reality. The problems in implementing these techniques can be broadly categorized as follows:

Resisting the stresses in compacted wall panels while tilting them into position.

Form and construction of roof structures.

Drainage problems when dwellings are somewhat below ground level, due to having been constructed out of the soil itself.

C. General principles of stabilized soil construction

Details of construction would of course vary depending upon the method employed but the general principles are identical with those of the traditional building materials such as brick, stone or concrete. The properties of the material impose one or two limitations irrespective of climate or local custom. These limitations are described as and where they occur in the discussion of the main operations in housebuilding.

a) Foundations: It has been shown that stabilized soil tends to be rather lower in strength than conventional materials such as brick or concrete. This means that stabilized soil walling will be slightly more susceptible to effects of foundation settlement than conventional materials and, therefore, foundations must be designed with at least as much care as would be given to conventional walling. Apart from this no special precautions are thought to be necessary.

b) Floors: Stabilized soil can provide an admirable flooring material for dwellings. The floors should be laid in two layers, base coat and top coat, to an overall thickness of not less than 3 inches, and preferably rather more to allow of straightening irregularities in the subfloor layer. Both these coats should be laid in strips not wider than 6 feet, marked off by strong wooden forms carefully levelled to the finished surface. The base coat may be laid without stabilizing medium and rammed to bring up to within 1½ inches of the final surface.[1] It is desirable to ram the top coat to a thickness slightly in excess of the finished thickness and then to scrape off carefully, using a straight edge laid across the forms to remove tool marks. A final light application of the rammer would then give the best finish obtainable. If the floor is to be laid in CINVA-RAM tiles or blocks, these must also be laid on a rammed base course.

c) Walls: In the main there will be no major difference in the use of stabilized soil walling as comparable with conventional material. A few precautions, however, are desirable.

i) The mortar for laying blocks should not be appreciably stronger than the blocks themselves. This will enable small movements due to shrinkage of the blocks to be accommodated in the joints without causing general cracking through the blocks.

ii) Realizing that the compressive and shear strengths of stabilized soil may often be lower than for normal brickwork and concrete blocks it is desirable to ensure that concentrated loads are well distributed on the wall.

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1. UNITED NATIONS: "Soil Cement, its use in Building", New York, 1964.

iii) Stabilized soil walling is more sensitive to changes in moisture content than traditional material. Special care is needed in the design and construction of features where exposure is particularly severe. Parapets should be provided with concrete coping and walls below ground level and up to a height of 12" above ground level should either be built in concrete or else provided with effective waterproofing on the outside. A cement-based paint on the lower part of the wall up to 12" above ground level should provide sufficient protection against rainwater splashing against it.

iv) External angles are particularly liable to injury by impact. It is therefore desirable that in work rammed in place a fillet should be placed in shuttering to provide a 45° chamfer. Purpose-made corner bricks and blocks may include a chamfer or alternatively the proportion of cement may be increased.

As far as structural design of walls is concerned it is suggested that the stabilized soil should be treated in exactly the same way as other masonry materials such as brick or concrete blocks. British Standard Code of Practice C.P.111 (Structural Recommendations for load-bearing walls) should be followed in this respect.

d) Roofs: Dwellings with walls constructed of stabilized soil can be roofed with any conventional form of construction. No special requirement is imposed. In view of the fact that stabilized soil is inherently somewhat sensitive to changes of moisture content it is recommended that where sloping roofs are used there should be a fairly generous overhang at eaves and verges. Care should be taken in the design of rainwater drainage to ensure that walls are not regularly flooded in heavy downpours from overflowing gutters and the like. There should however be no fear of any catastrophic consequences from an occasional flooding due to abnormal rainfall because adequate durability of the material is proved from the experiments in this study.

In considering how far stabilized soil can itself provide a solution to the roofing problem of the low cost dwelling, it may be concluded from first principles that the scope of the material is limited. There are basically only three possible solutions:

a) The beam or slab of reinforced concrete, steel or timber.
   A variant of (a) in the form of trussed construction in sloping roofs of timber or steel and, recently, aluminium.

b) The catenary.

c) The dome or vault.

Various attempts have been made in many countries to find some economical solution to roofing problems, yet reinforced concrete slab remains the most commonly used method of roof construction with the traditional materials like burnt brick in the Indus Basin.

As far as the use of stabilized soil for this purpose is concerned it is just possible that a first class stabilized soil might provide a substitute for concrete in reinforced concrete. It is nevertheless doubtful that adequate strengths can be attained in this material for this purpose, but it may be possible to use it as infill in reinforced concrete joists in a similar way to hollow pot construction.

There hardly seems any place for this material in trussed construction. The catenary is the direct opposite of the dome as it induces almost exclusively tensile forces offering no use for stabilized soil.

The only other alternative left is the dome and vault and here stabilized soil may provide a solution given sufficient attention. A substantial dome or vault ring could be designed to function well within the stress range of a good stabilized soil. The trend of development of roofs over the years has, however, been away from the dome and vault. Though they are basically structures involving mainly compressive forces, domes and vaults exert a powerful horizontal thrust at their springing. This horizontal force requires adequate buttressing in the walls which soon become uneconomic, or else it must be taken by steel tie-rods in the case of a vault, or by a steel ring, with or without tie-rods, in the case of a dome. Given a thorough understanding of these problems and a durable material like stabilized soil, a project like Alqurna must have been a commendable example of the suitability of this material for dome and vault roof construction.[1]

There is another structural form which introduces no appreciable tensile forces and is quite suitable for exploitation in stabilized soil. This is the parabolic arch and it is the form which theoretically involves entirely compressive forces in the ring. In India the experimental houses using the parabolic vault in stabilized soil have stood in use since their construction in 1947.[2] The structure combines roof and walls and merely needs incorporation of a waterproofing to exclude rain. Development of this type, however, has the psychological disadvantage that it is unfamiliar, and therefore unpopular with the general public. Also it still requires the hand of a skilled architect to produce aesthetically satisfactory combinations of vaults, and to transform a basic structural shape into a habitable and attractive dwelling. The parabolic vault exerts an outward horizontal thrust at its base and this must be adequately restrained, failing which the vault will collapse. Thus a special foundation problem is imposed.

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1. See page 47.

2. Experiments in stabilized soil vaulted housing at The Building and Roads Research Laboratory, Karnal, East Panjab, Indian Roads Congress 1965.

A number of thin shelled reinforced concrete roofs for housing were developed by Baroni in Israel.[1] The object was to reduce the consumption of steel and concrete to the minimum. These experiments have shown that thin reinforced concrete shells can be used successfully with small stabilized soil houses and that curvilinear surfaces enable maximum advantage to be taken of thin shells. The practical utilization of the thin shell roof calls for a simple, easily withdrawable set of shuttering and by the Baroni method the roof must be built first on piers and reinforced concrete columns, the walls being filled in afterwards. This has the disadvantage that the potential strength of the walls for sustaining the roof-loads is put to no useful purpose. Feasibility of making hyperbolic paraboloid thin shells in sections and lifting them into position should also prove to be a fruitful field of experimentation.

The thin shell, however, has neither good insulation nor appreciable thermal capacity, which would make it very uncomfortable in the hot climate of the Indus Plains. Additional thermal treatment would therefore have to be developed. Use of stabilized soil for this purpose could be considered.

It is apparent from this brief discussion that a great deal of work needs to be done in the constructional aspects of soil stabilization, particularly in the development of a suitable form of roof construction comparible with low strengths of this material. The application of stabilized soil to low-cost housing, however, does not have to wait for the outcome of these developments. Although it has the potential for adaptability to more progressive and efficient building techniques that may be developed in due course, it can as easily and effectively be used in any of the present forms of construction.

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